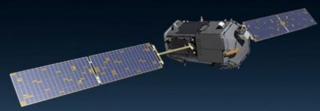


OCO-2 Report

OCO-2 Status
Maximum Radiance Trends
Highlights of OCO-2 Science Team Meeting
TanSat Status
Introduction to GeoCarb

David Crisp

Jet Propulsion Laboratory,
California Institute of Technology

15 February, 2017

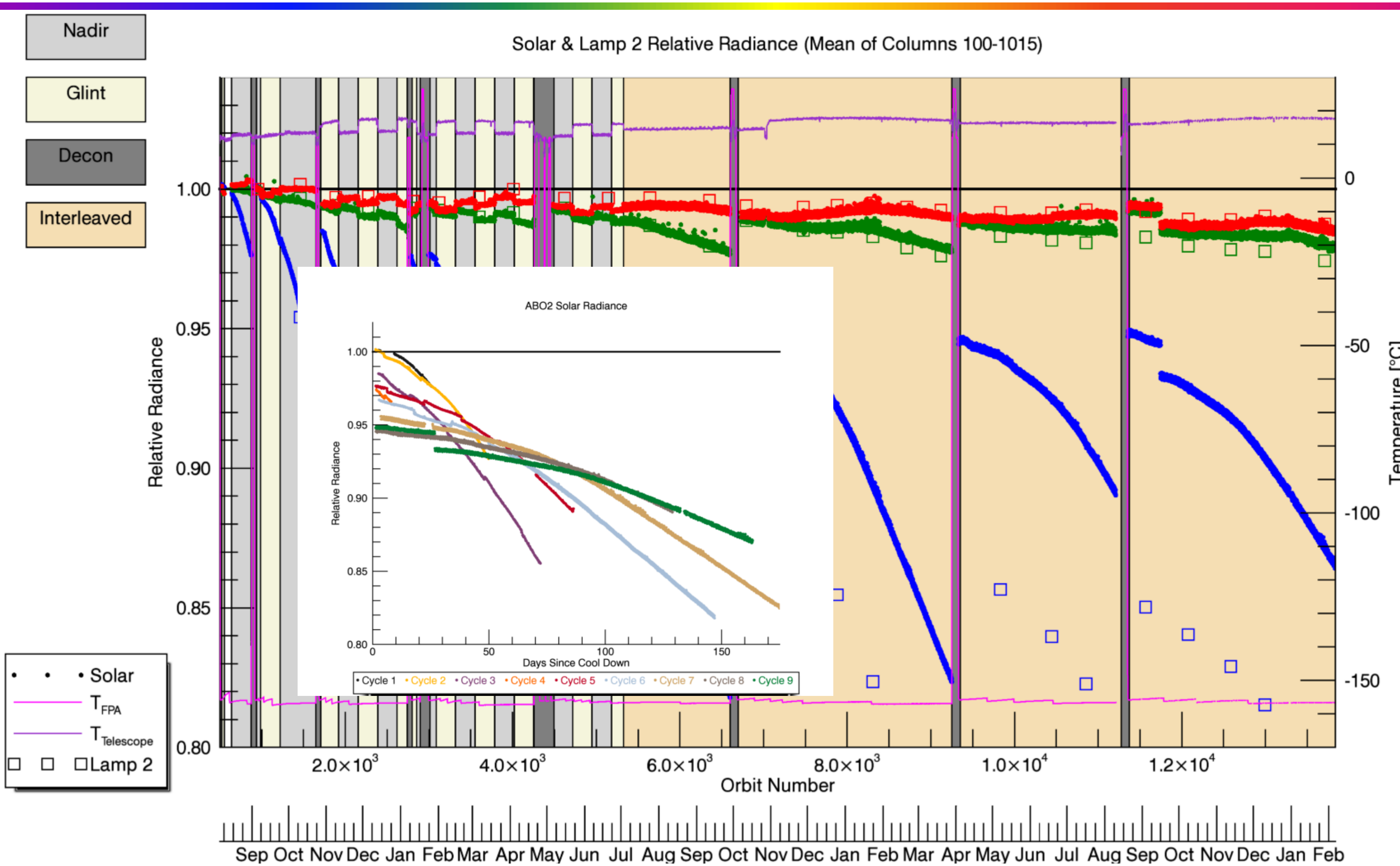
Overview

- **OCO-2 Status and Near-Term Plans**
- **Version 8 Progress and Plans**
- **OCO-2 Maximum Radiance Trends**
- **Highlights of the October 2016 Science Team Meeting**
- **New Missions**
  - **TanSat Status**
  - **Introduction to the Gaofen-5 Mission**
  - **Introduction to the GeoCarb Mission**
- **Upcoming Meetings**

OCO-2 Status

- Observatory Status: Nominal
  - Last drag make-up maneuver (DMUM#14) - 13 January 2017
    - Next scheduled Drag Make-Up Maneuver – 27 March 2017
      - Part of 2017 inclination adjust maneuver campaign
- Instrument Status: Nominal
  - Next Decon planned for February 21 – March 1, 2017
- Science and Validation
  - Version 7r delivered through November 2016.
  - Continued testing of Version 8 build
    - Preliminary test suite completed, improvements ongoing
  - ACOS B7.3 production complete and documentation in process

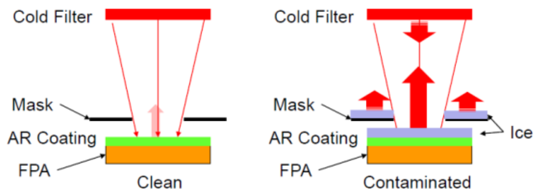
OCO-2 Instrument Trending

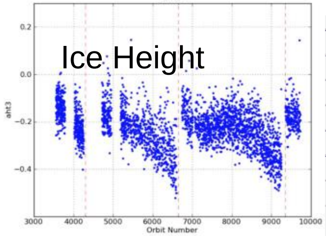


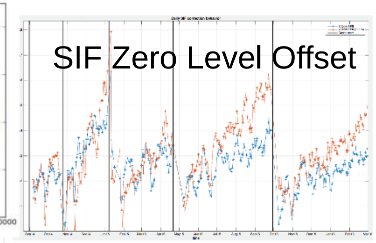
Ice accumulation rate on the ABO2 FPA continues to decrease over time.

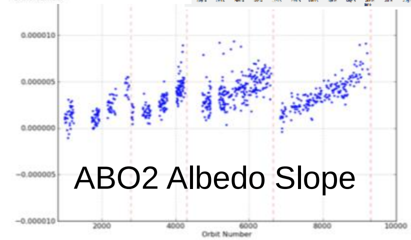
Instrument Calibration

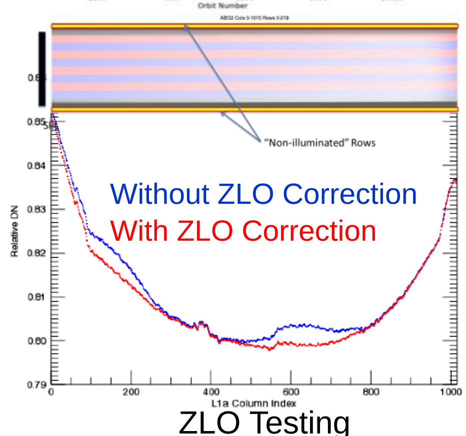
- The calibration team is characterizing the zero level offset (ZLO) associated with ice accumulation on the A-band (ABO2) focal plane array
- The ZLO introduces artifacts in the SIF, albedo, and aerosol retrievals
- Significant progress has been made in characterizing the ZLO and its changes with contamination level
- A correction process has been developed to remove the ZLO from the L1B radiances
- This method is currently being tested for use in the Version 8 (v8) algorithm





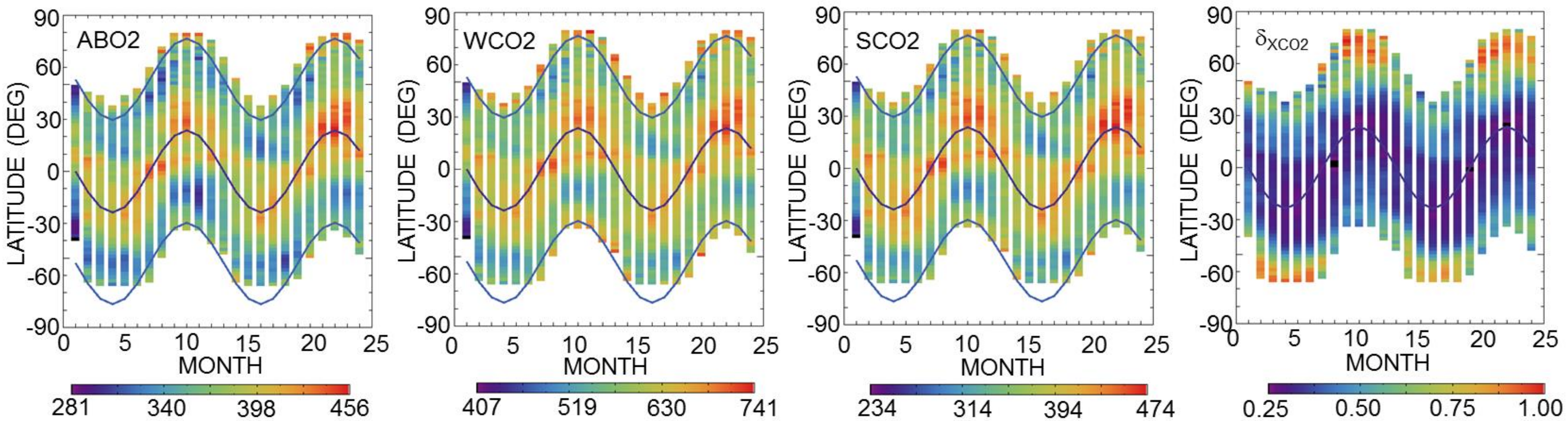






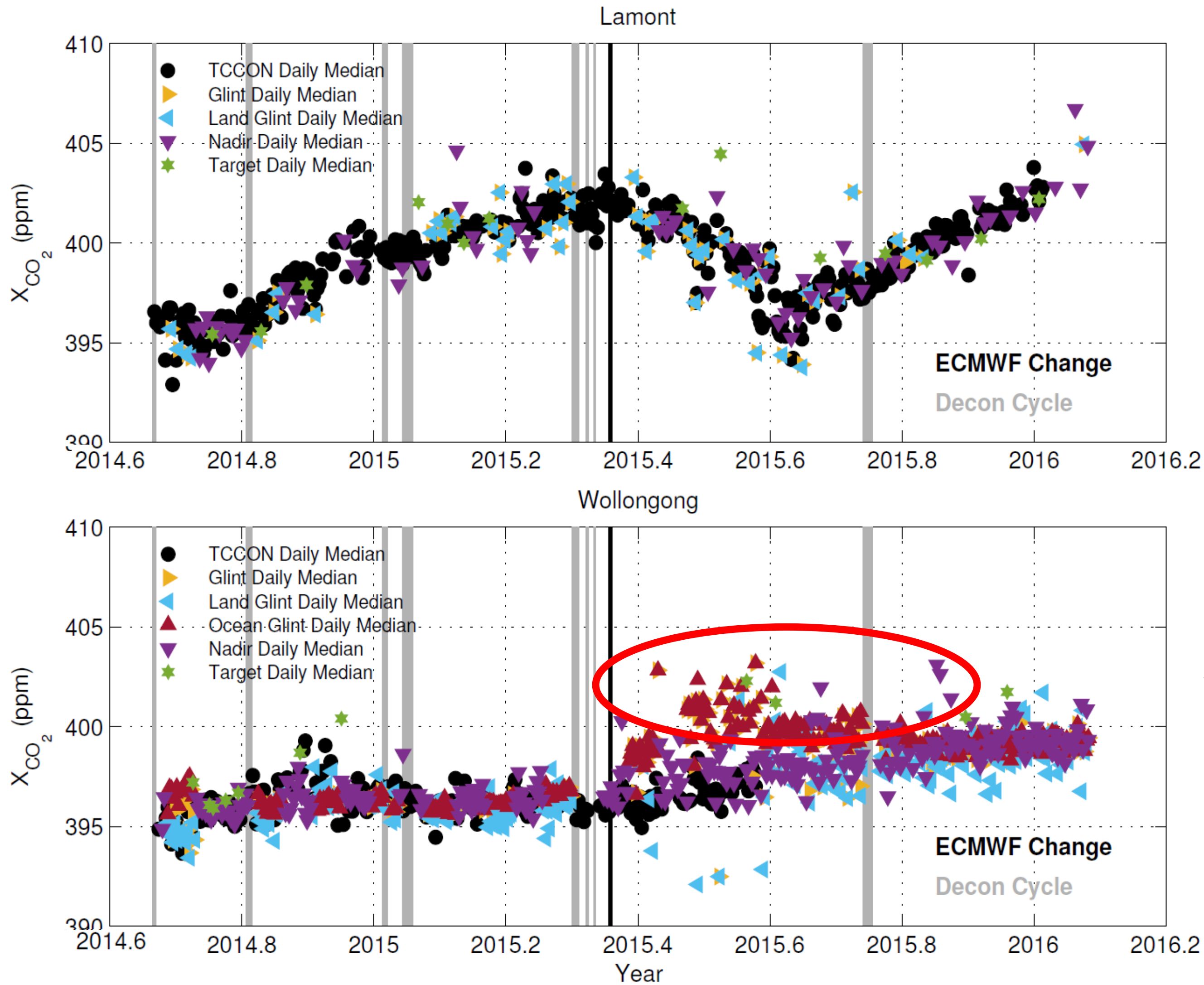
OCO-2 Glint Performance

- Glint observations provide high SNR at solar zenith angles as high as 70°.
- The principle limit on the northern hemisphere latitude range is optically-thick clouds
- Clouds also limit the coverage of high latitudes in the southern hemisphere, but the v7 data product also includes a 65° S "Ice" cut-off that limits coverage at higher southern latitudes



Latitude-time (Hovmoller) diagrams showing the single-sounding SNR and in the ABO2, WCO2, and SCO2 bands, and the resulting signal sounding random error in OCO-2 X_{CO2} for cloud-free glint observations (v7r Lite Files).

Temporal Changes in X_{CO2}: Comparisons with TCCON and other Standards



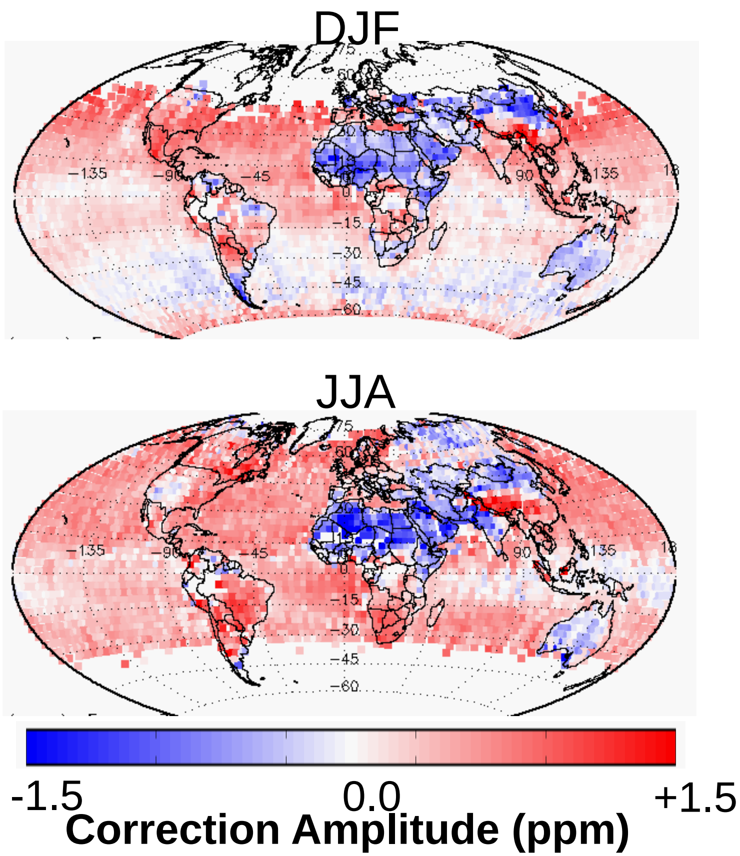
OCO-2 X_{CO2} estimates generally agree with those from TCCON, with errors < 1.5 ppm prior to bias correction and < 0.5 ppm after bias correction

However, much larger biases are seen for a small fraction of the ocean glint measurements at high southern latitudes during southern winter.

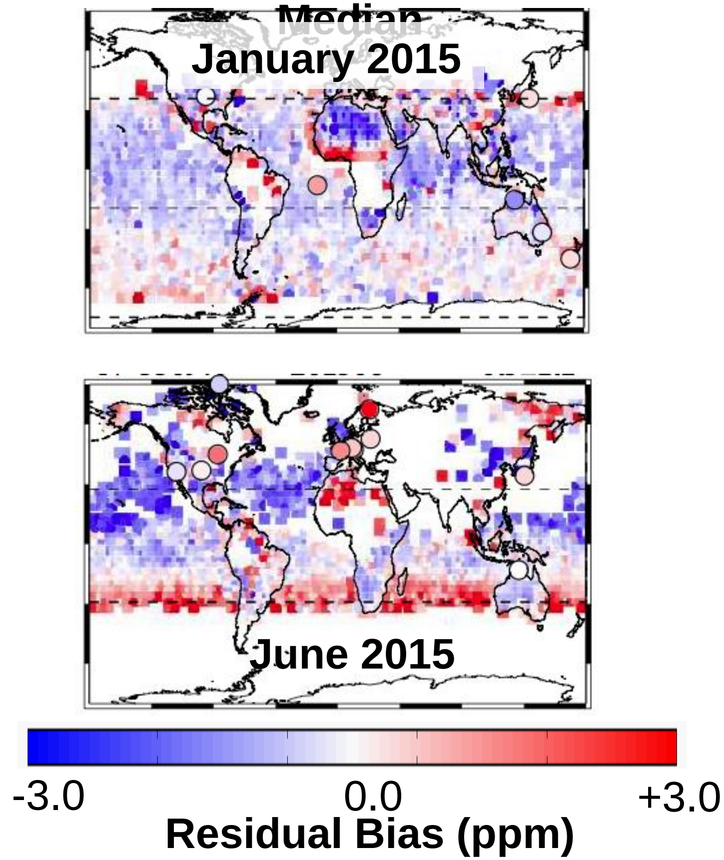
(Wunch et al., ATMD, 2016)

Bias Corrections in the V7 Lite Products

Bias correction amplitude in Lite files



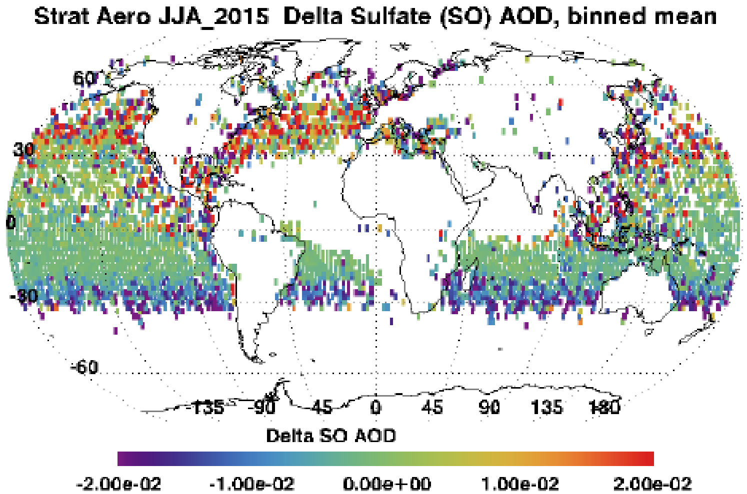
Residual bias vs Multi Model Median

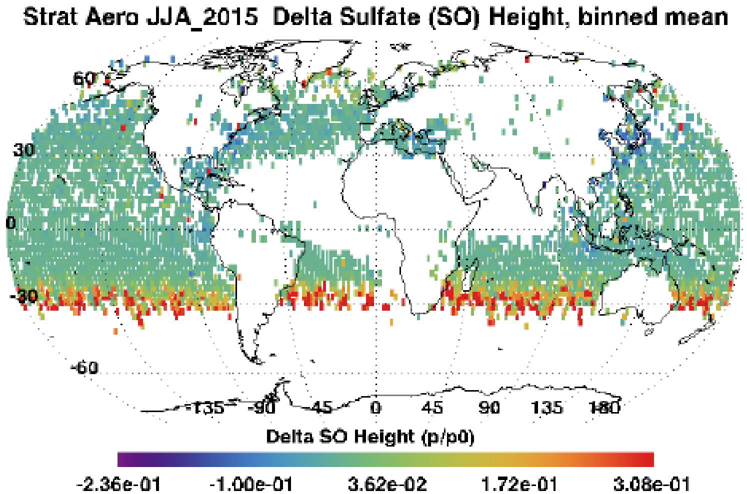


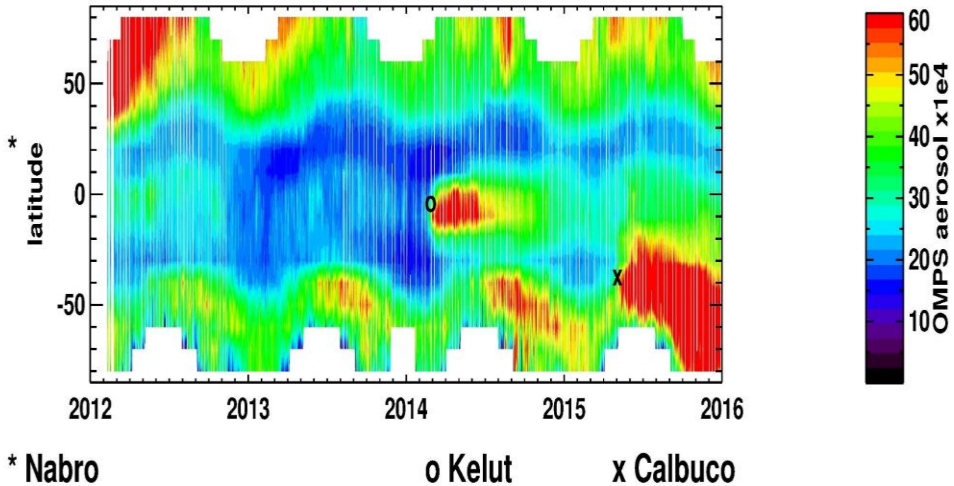
The Southern hemisphere glint bias is not captured by the bias correction process

But it is seen in comparisons to medians of ensembles of carbon cycle models

The 2015 Data affected by the Chilean Calbuco volcano eruption



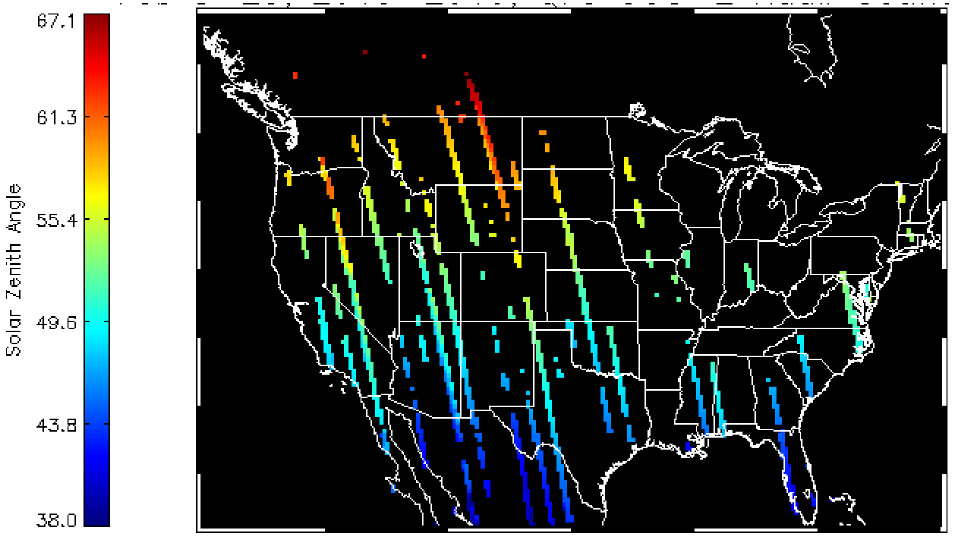




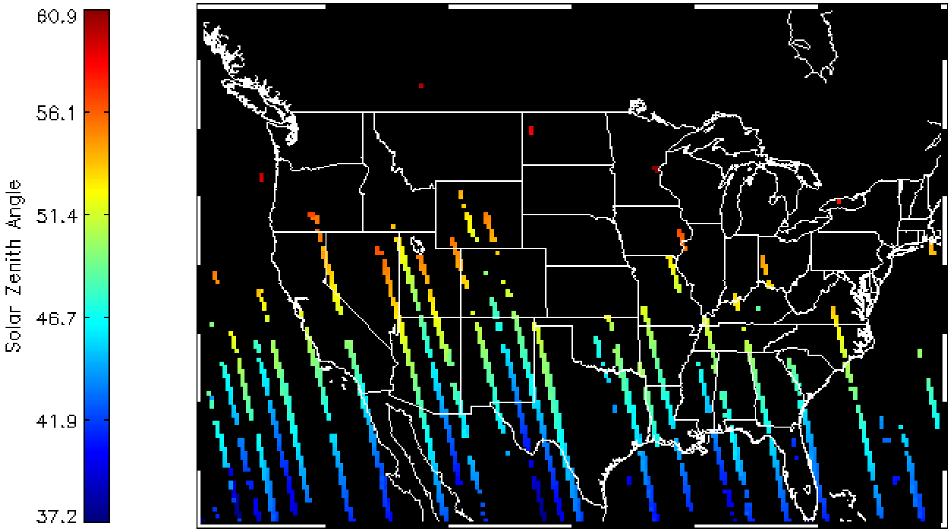
OMPS detected a significant enhancement in stratospheric H_2SO_4 aerosols in mid 2015

Nadir vs Glint Coverage over Land

February 8-25 2016 OCO-2 Nadir



February 8-25 2016 OCO-2 Glint

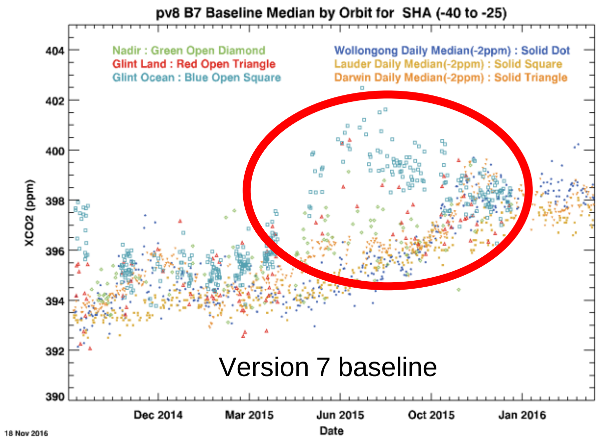


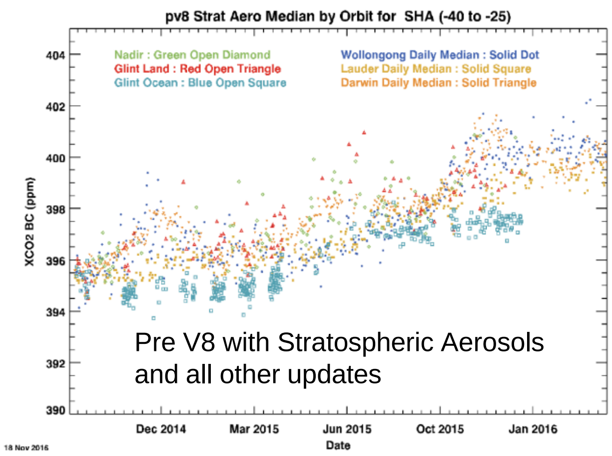
Nadir observations provide better coverage over continents, especially in the winter hemisphere due to the larger atmospheric air mass and larger probability of cloud contamination. The plots above show the coverage over North America for a 16-day repeat cycle in mid February (8-25) of 2016.

Version 8 Progress and Plans

Version 8 Testing

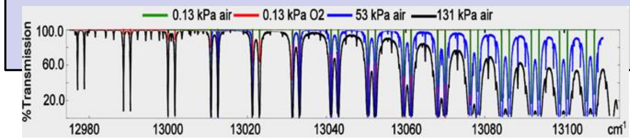
- **Pre-Version 8 Tests completed**
  - Calibration updates (slow degradation, etc.)
  - pre-V8 baseline: Revised L1B + ABSCO 5.0
  - updated surface BRDF
  - TCCON CO_2 prior
  - updated cirrus cloud prior
  - Stratospheric aerosols
  - MERRA-2 vs ECMWF Met prior
  - Rescale SCO2 ABSCO



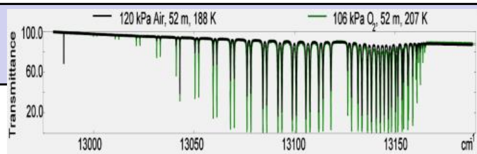


- **Tests to go**
  - Daily aerosol prior, 65 S restriction removed
  - Zero level offset correction, Footprint bias, CO_2 Constraint

Improved Gas Absorption Cross Sections Reduce Bias



Cavity Ringdown Spectroscopy

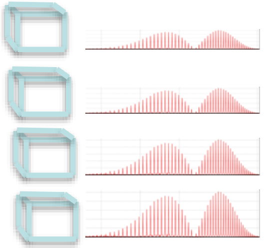


Fourier Transform Spectrometer

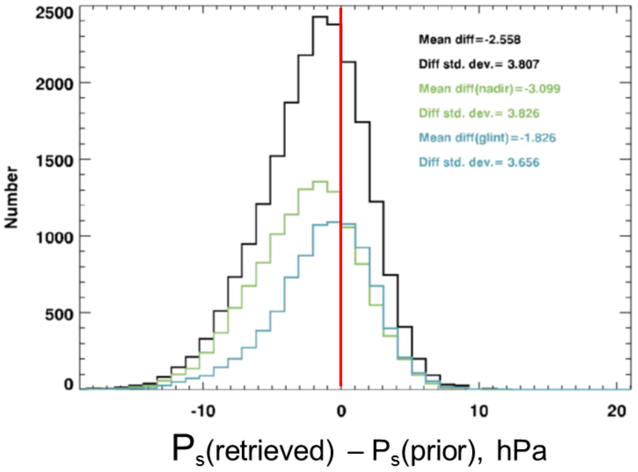
TCCON spectra

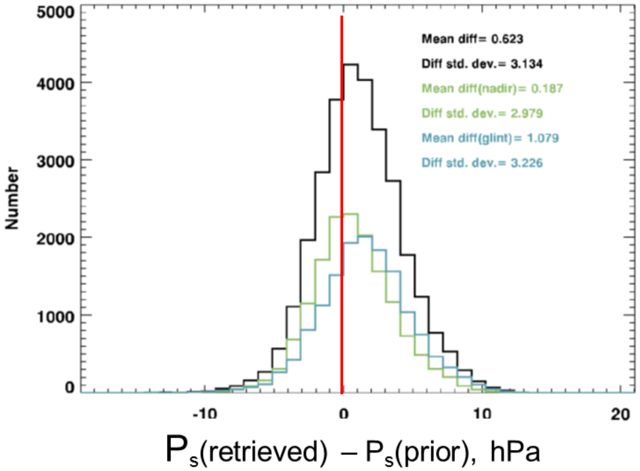
Multispectrum fitting analysis

ABSCO Tables



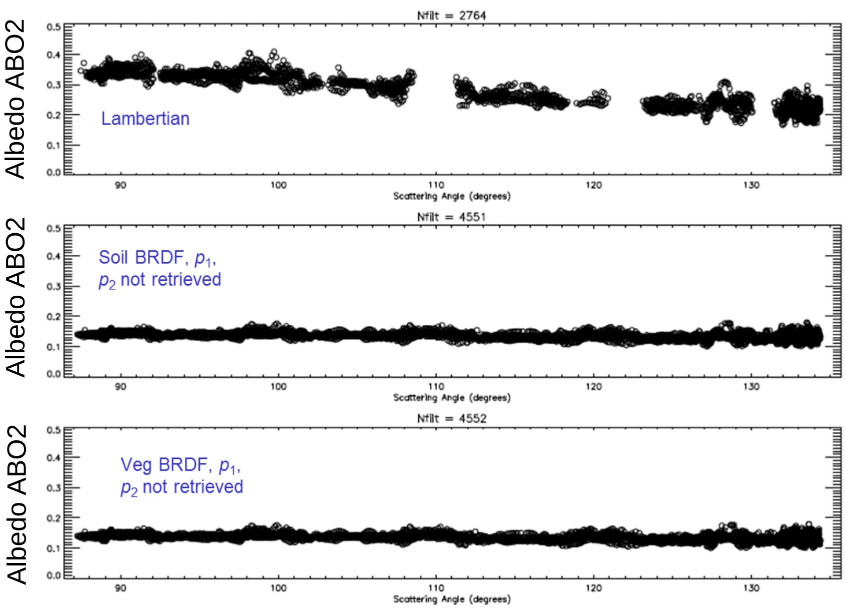
Reduced Bias



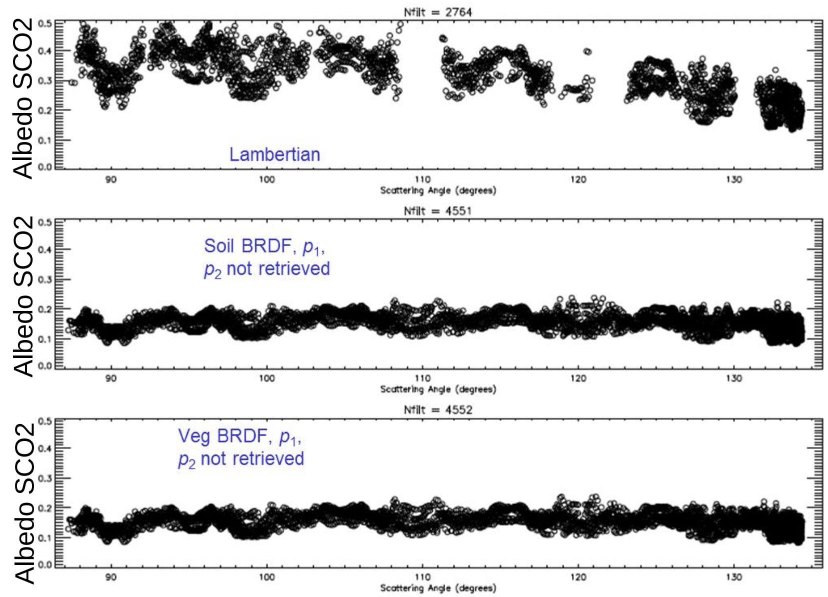


Vivienne Payne et al. (this session)

Improved BRDF Model Testing: Lamont Target, Orbit 1362 (1)



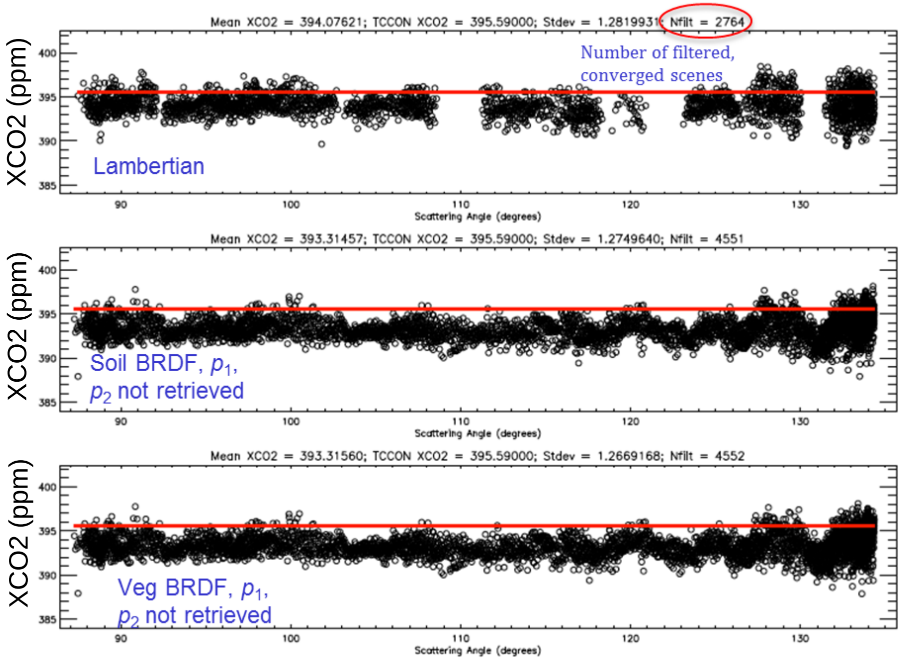
Surface reflectance retrievals in the O2 A-band using a Lambertian BRDF (top) are compared to those using a simplified Soil (middle) and Vegetation (bottom) BRDF

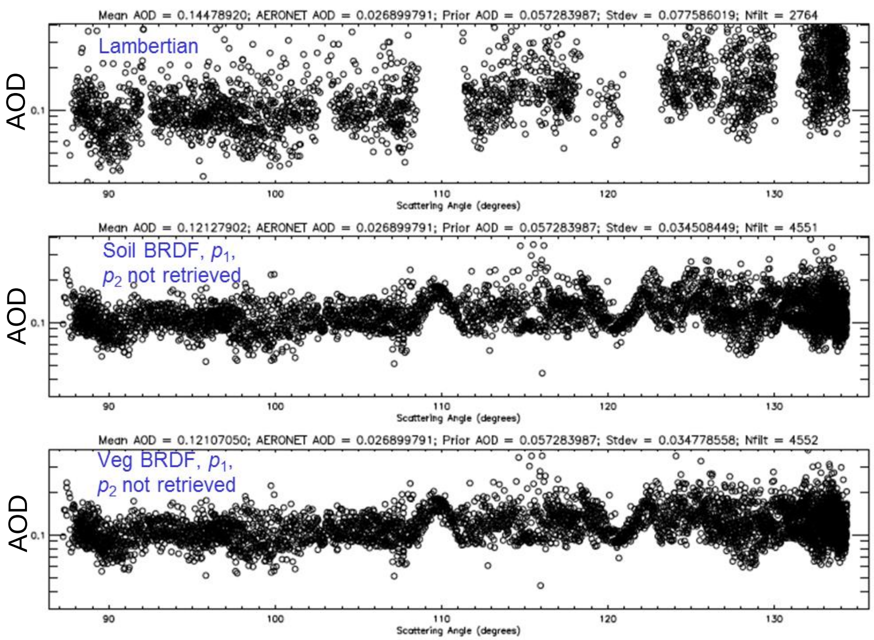


Surface reflectance retrievals in the Strong CO2 band using a Lambertian BRDF (top) are compared to those using a simplified Soil (middle) and Vegetation (bottom) BRDF

Both the simplified Soil and Vegetation BRDF functions reduce the scatter and systematic, observation-angle-dependence of the surface reflectance when compared to the current Lambertian surface albedo.

Improved BRDF Model Testing: Lamont Target, Orbit 1362 (2)





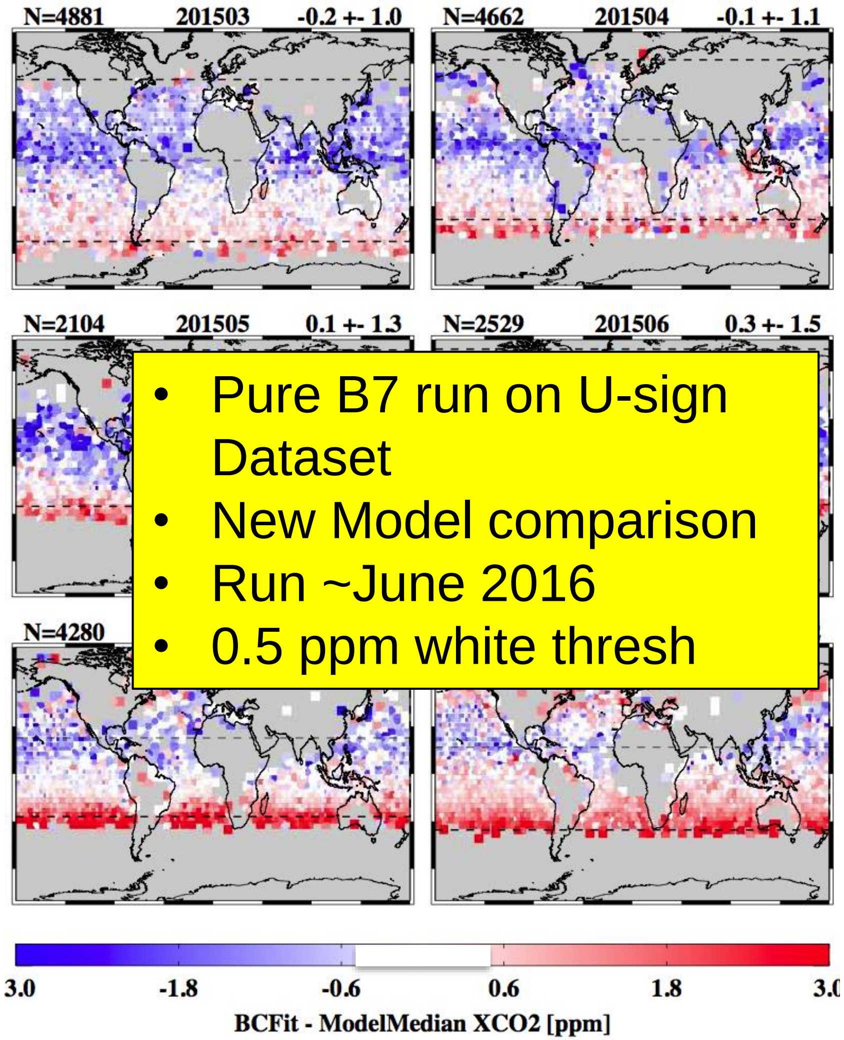
XCO2 retrievals using a Lambertian BRDF (top) are compared to those using a simplified Soil (middle) and Vegetation (bottom) BRDF

Aerosol optical depth retrievals using a Lambertian BRDF (top) are compared to those using a simplified Soil (middle) and Vegetation (bottom) BRDF.

Both the simplified Soil and Vegetation BRDF functions reduce the scatter and increase the yields for X_{CO2} and aerosol optical depth retrievals when compared to the current Lambertian surface albedo.

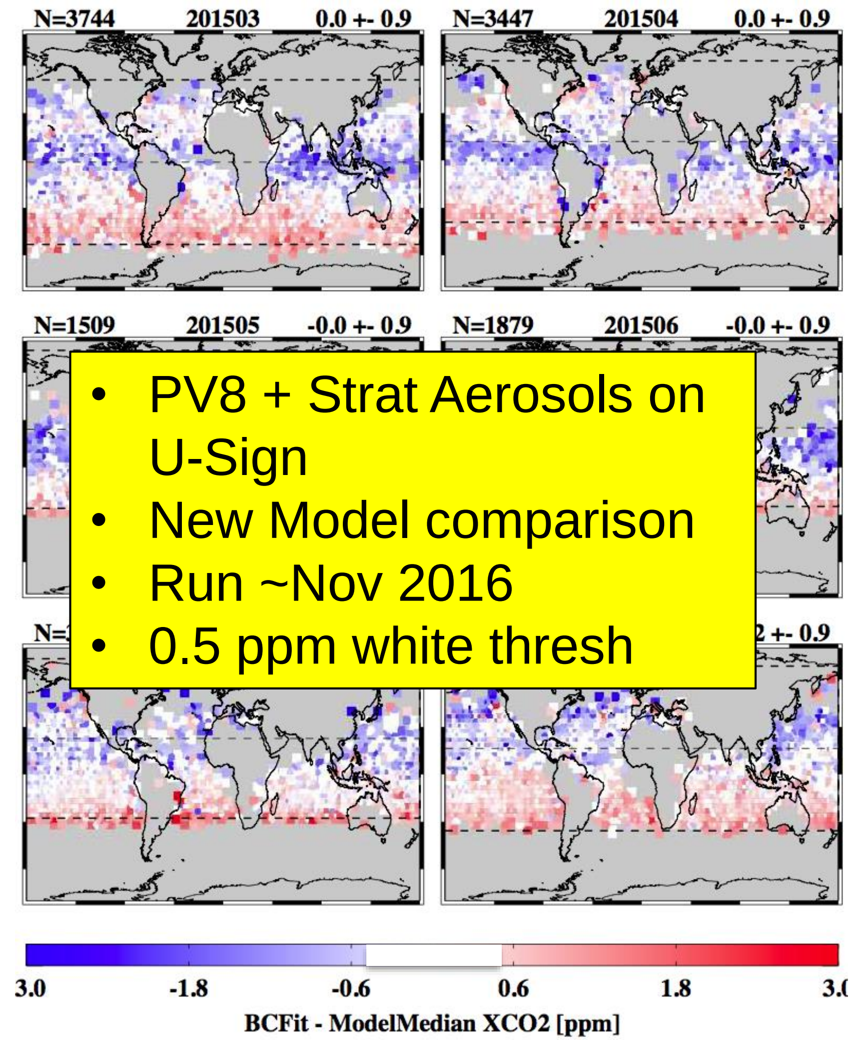
Stratospheric Aerosol

Without Strat Aerosols



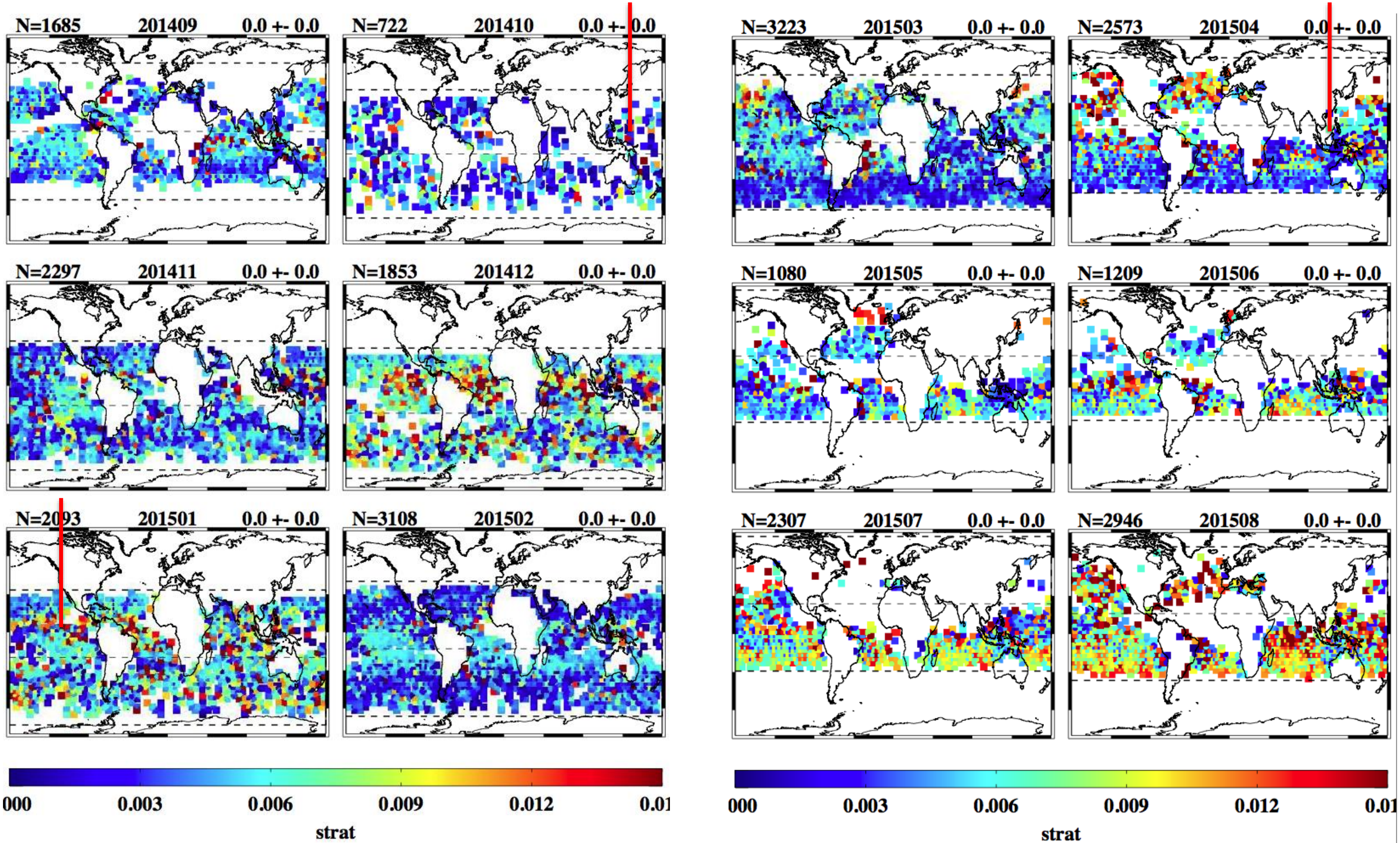
- Pure B7 run on U-sign Dataset
- New Model comparison
- Run ~June 2016
- 0.5 ppm white thresh

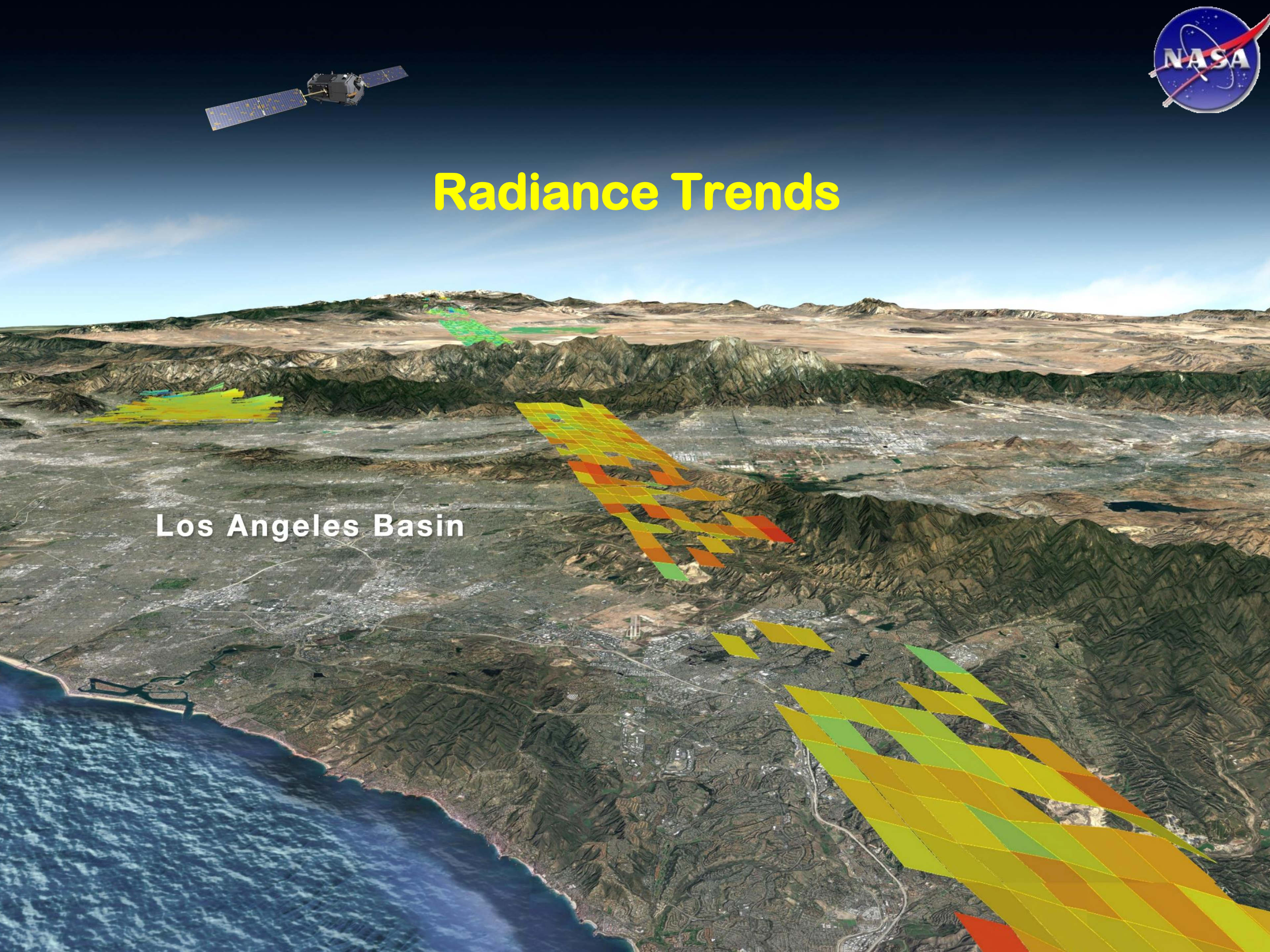
With Strat Aerosols



- PV8 + Strat Aerosols on U-Sign
- New Model comparison
- Run ~Nov 2016
- 0.5 ppm white thresh

Retrieved Strat Aerosol Optical Depths




Radiance Trends
Los Angeles Basin

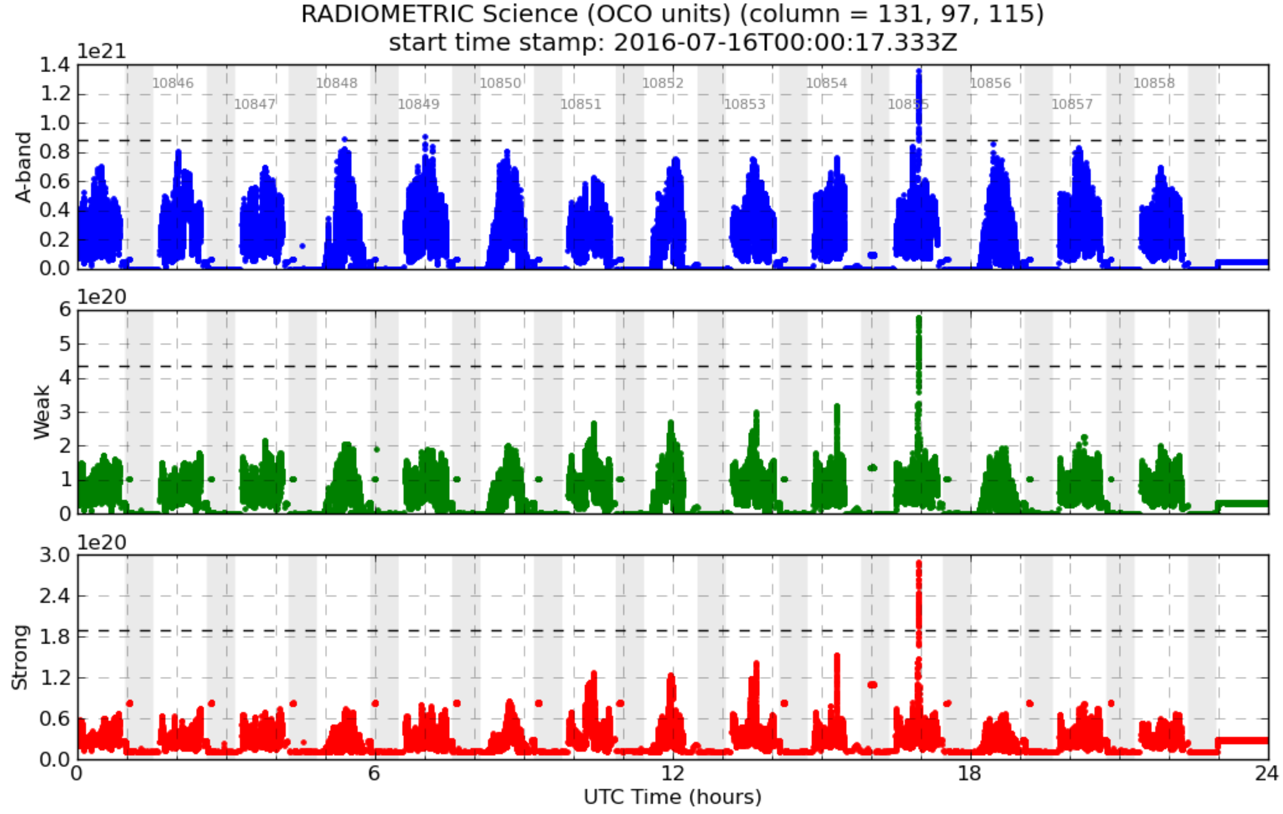
Radiance Trending

- The OCO-2 calibration team routinely trends the radiance levels observed in continuum regions of each of the 3 spectral channels
  - Reported in standard L1B units (photons/s/m^2/sr/µm) as well as DN
  - Daily, monthly, and full-mission ("forever plots") are generated

- These results provide a record of saturation events as well as the time dependence of the radiometric performance.
  - Saturation events are usually associated with anomalously-bright ocean (or lake) glint observations at low latitudes
  - These events typically occur more often during the northern hemisphere summer (June – August) associated details of the OCO-2 orbit and glint viewing geometry

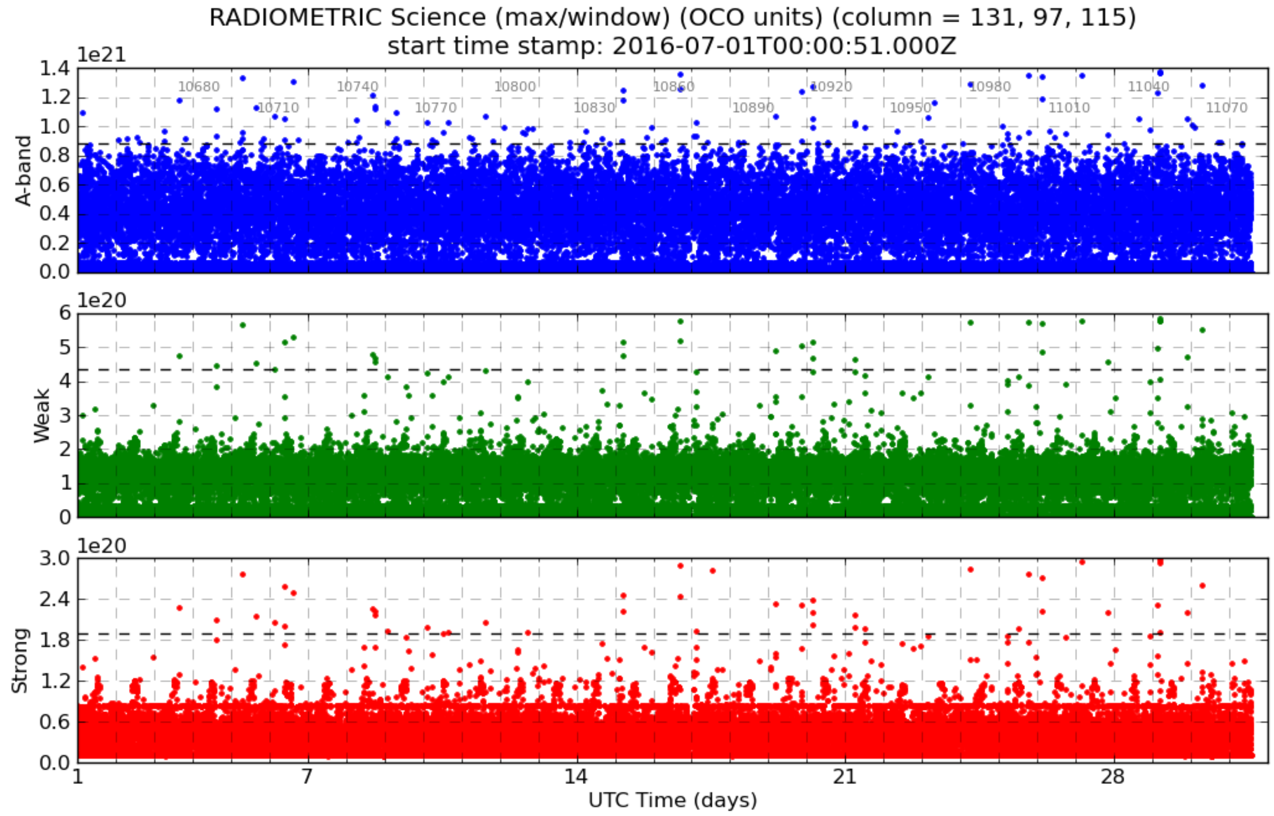
- Examples of daily, monthly and full-mission records are shown on the following slides

Daily Radiance Records



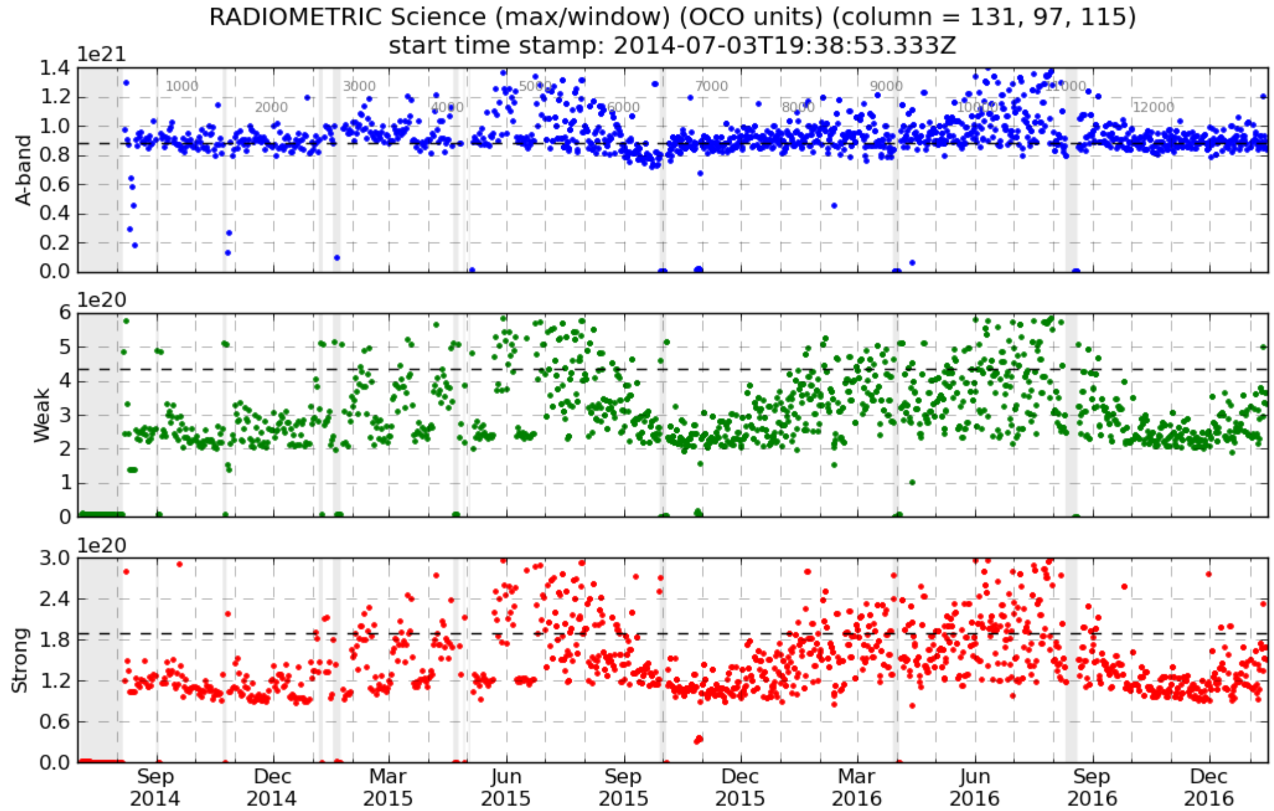
Daily radiance records are shown for the O_2 A-Band (top), 1.61-µm Weak CO_2 band (middle), and 2.06-µm CO_2 band (bottom) for 7 July 2016. Orbit numbers are shown in light grey (glint-odd, nadir-even) and grey bars indicate eclipse times. Maximum measureable signals levels for each band are indicated by a horizontal dash line. An anomalously bright glint observation was record at 1700 UTC.

Monthly Radiance Records



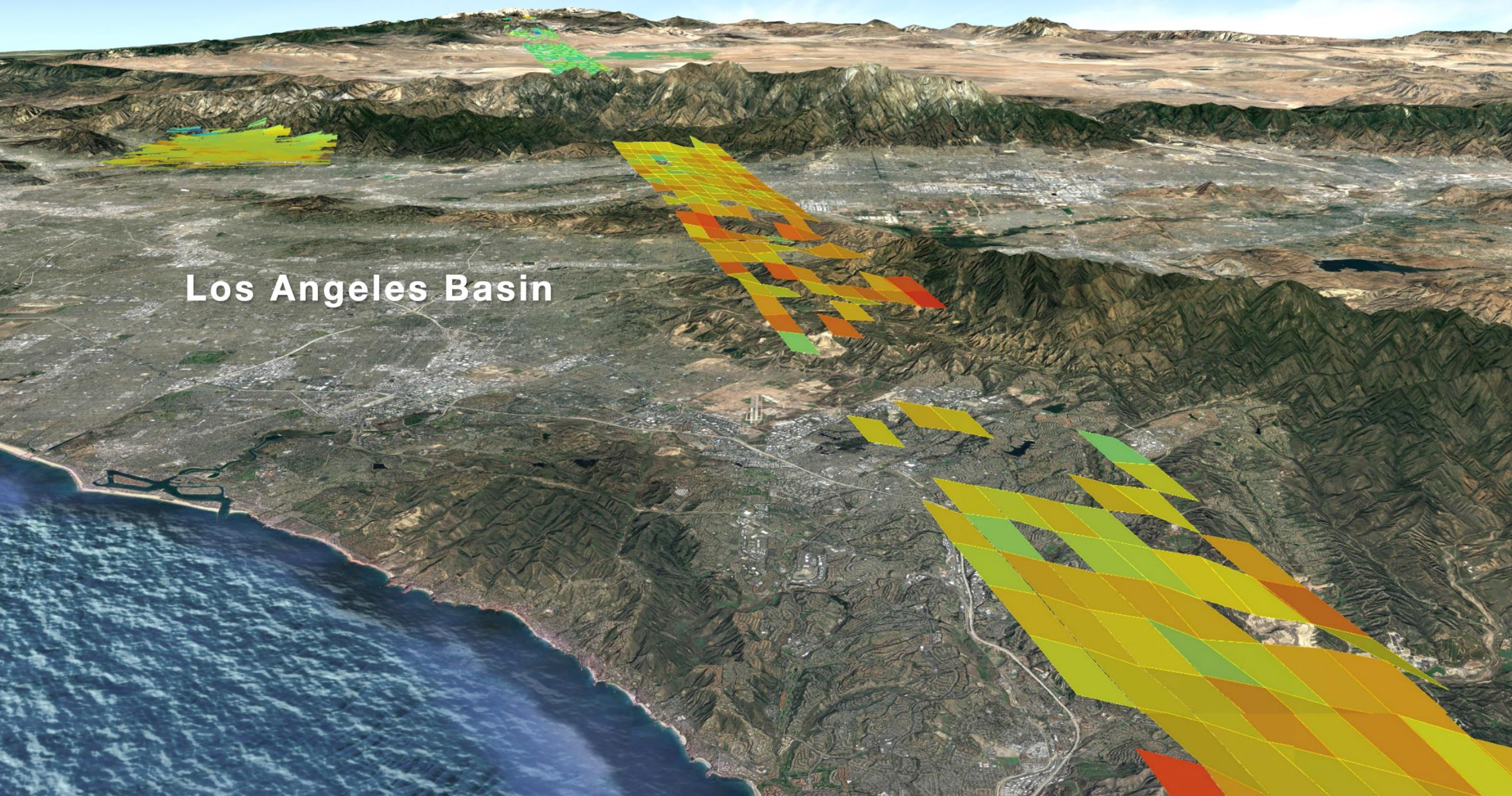
Radiance levels for the O_2 A-Band (top), 1.61-µm Weak CO_2 band (middle), and 2.06-µm CO_2 band (bottom) are shown for July 2016. Maximum measureable signals levels for each band are indicated by a horizontal dash line. Observations exceeding this level are typically associated with anomalously bright glint observations at low latitudes.

Radiance Levels over 30 Months



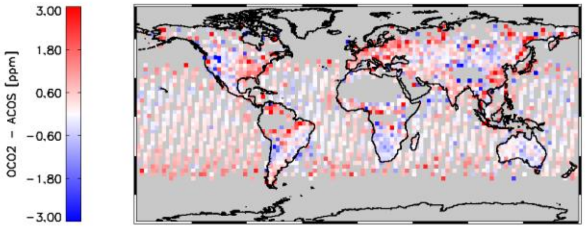
Radiance levels for the O_2 A-Band (top), 1.61-µm Weak CO_2 band (middle), and 2.06-µm CO_2 band (bottom) are shown for the first ~30 months of the OCO)-2 mission. Maximum measureable signals levels for each band are indicated by a horizontal dash line. Observations exceeding this level are typically associated with anomalously bright glint observations at low latitudes.

Highlights of the October 2016 OCO-2 Science Team Meeting

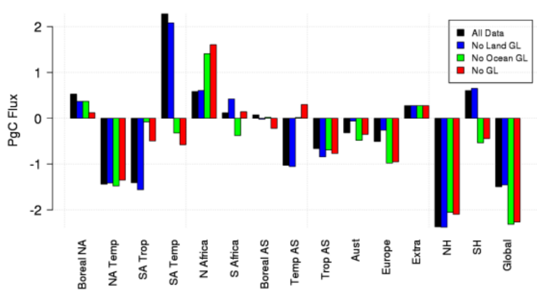


Highlights of the October 2016 OCO-2 Science Team Meeting

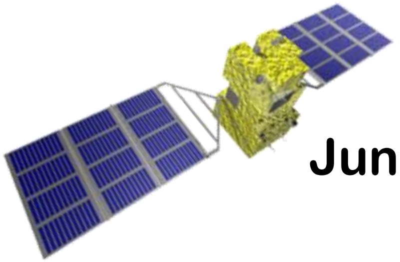
- The OCO-2 Science Team Meeting was hosted by the National Center for Atmospheric Research (NCAR) in Boulder, CO on 25-27 October 2016
  - Over 70 science team members and affiliates participated
  - Followed by "End of Prime Mission Review"
- The agenda included reports from all OCO-2 Theme groups (Calibration, Level-2 Algorithm, ABSCO, Cloud/Aerosol, Flux Inversion, Local Sources, Uncertainty Quantification)
- Individual science team members reported work in 2-minute speed talks and posters
- Focus on the Global Flux Inversion, the Version 8 product, and publications



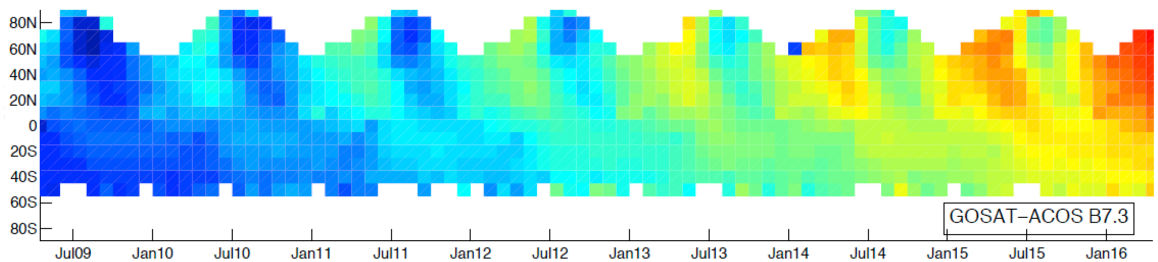
OCO-2 v7 vs ACOS/GOSAT B7.3



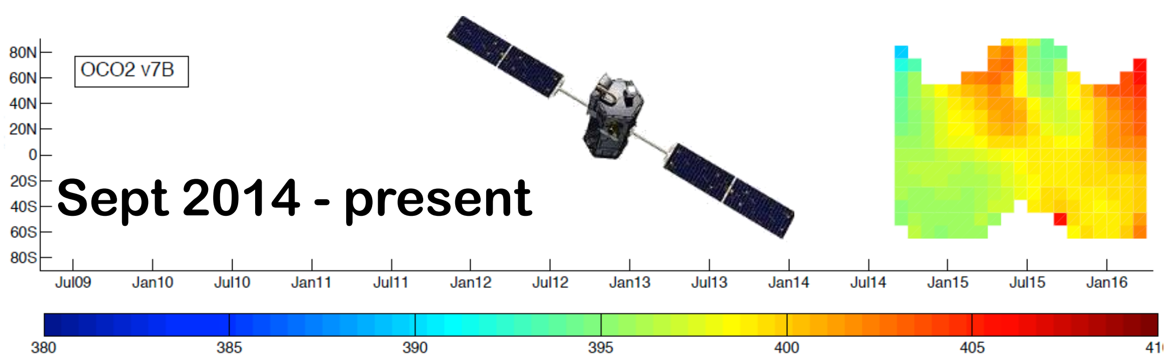
ACOS/GOSAT B7.3, and OCO-2 v7 XCO2



June 2009 - present

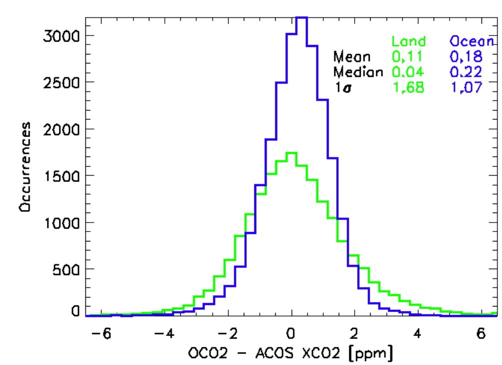


Sept 2014 - present

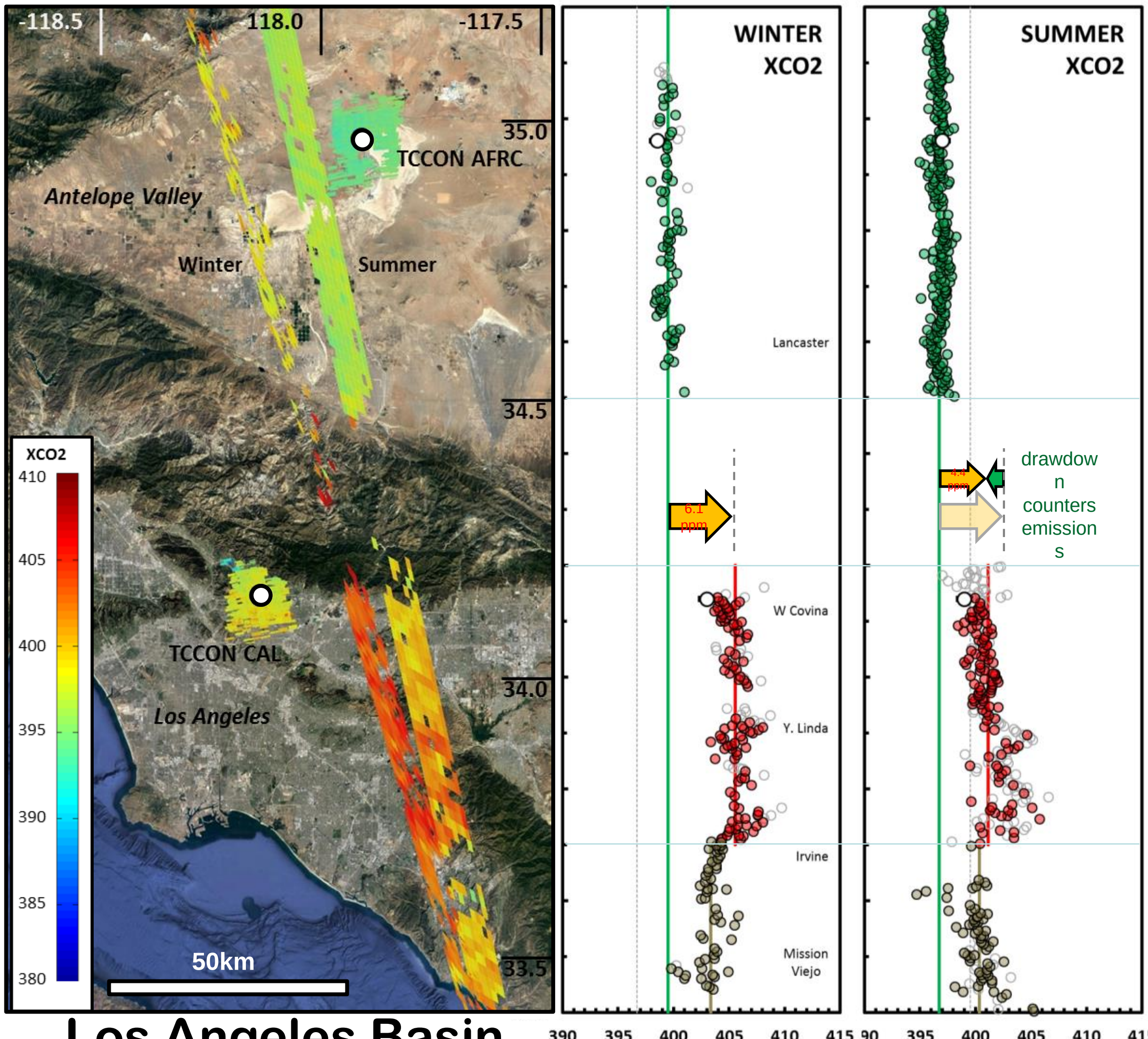


TCCON and other standards have been used to cross validate OCO-2 and GOSAT X_{CO2} to extend the climate data record

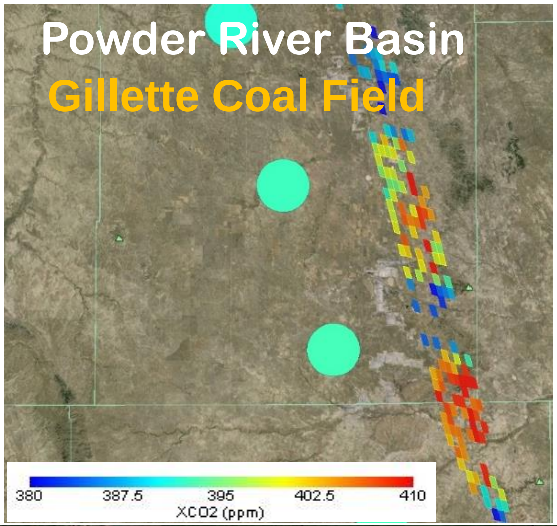
- The magnitude of differences between GOSAT-ACOS B7.3 and OCO2 v7r are within ±1 ppm for overlap regions

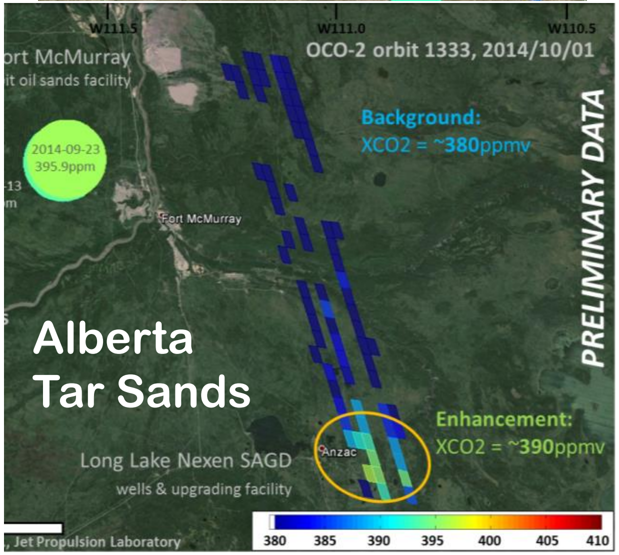


Localized Sources



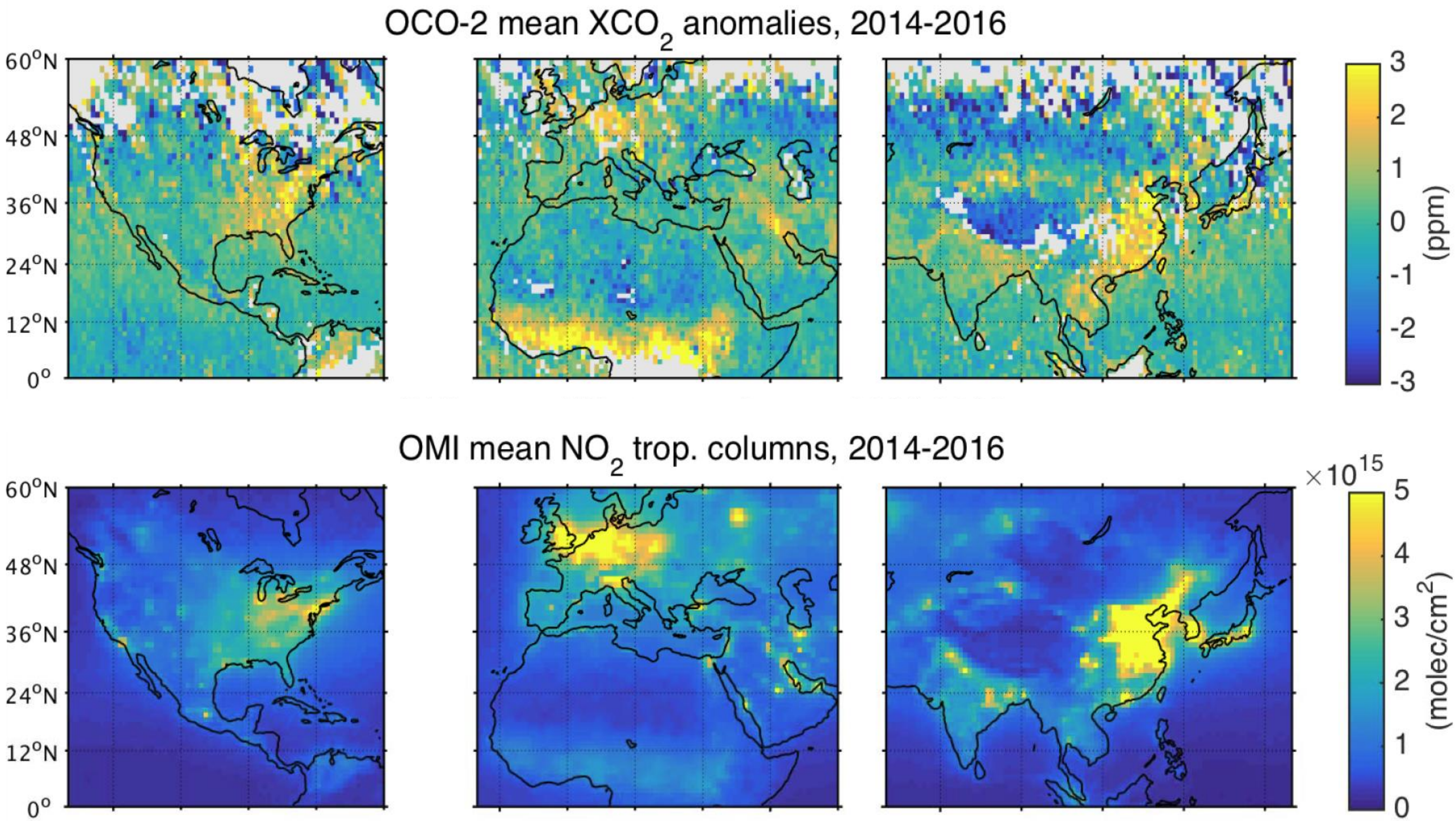
Los Angeles Basin





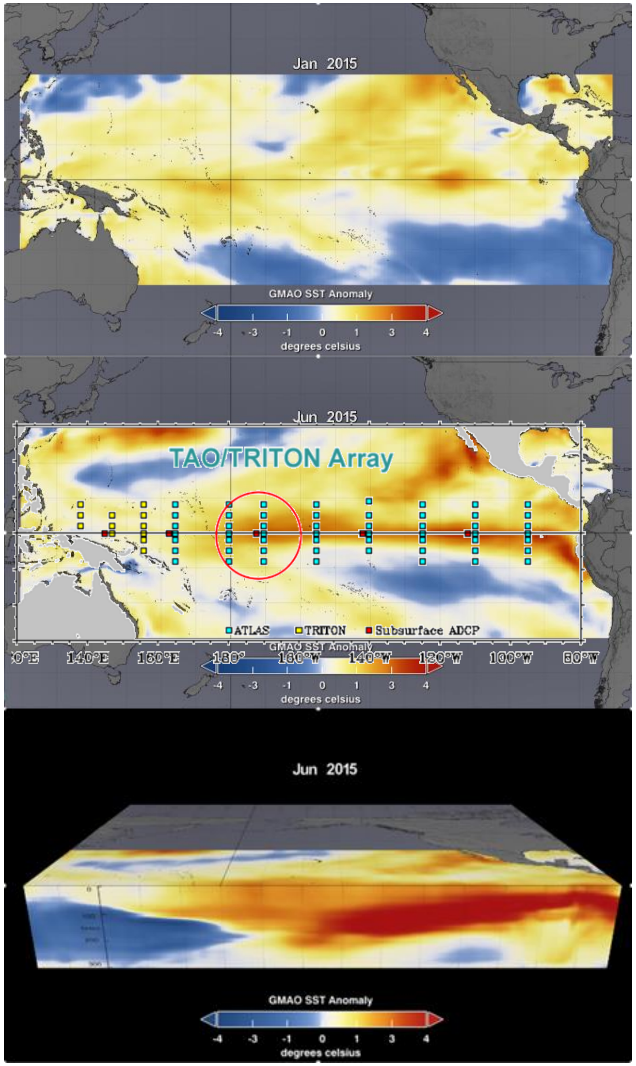
Florian Schwandner et al.(Submitted)

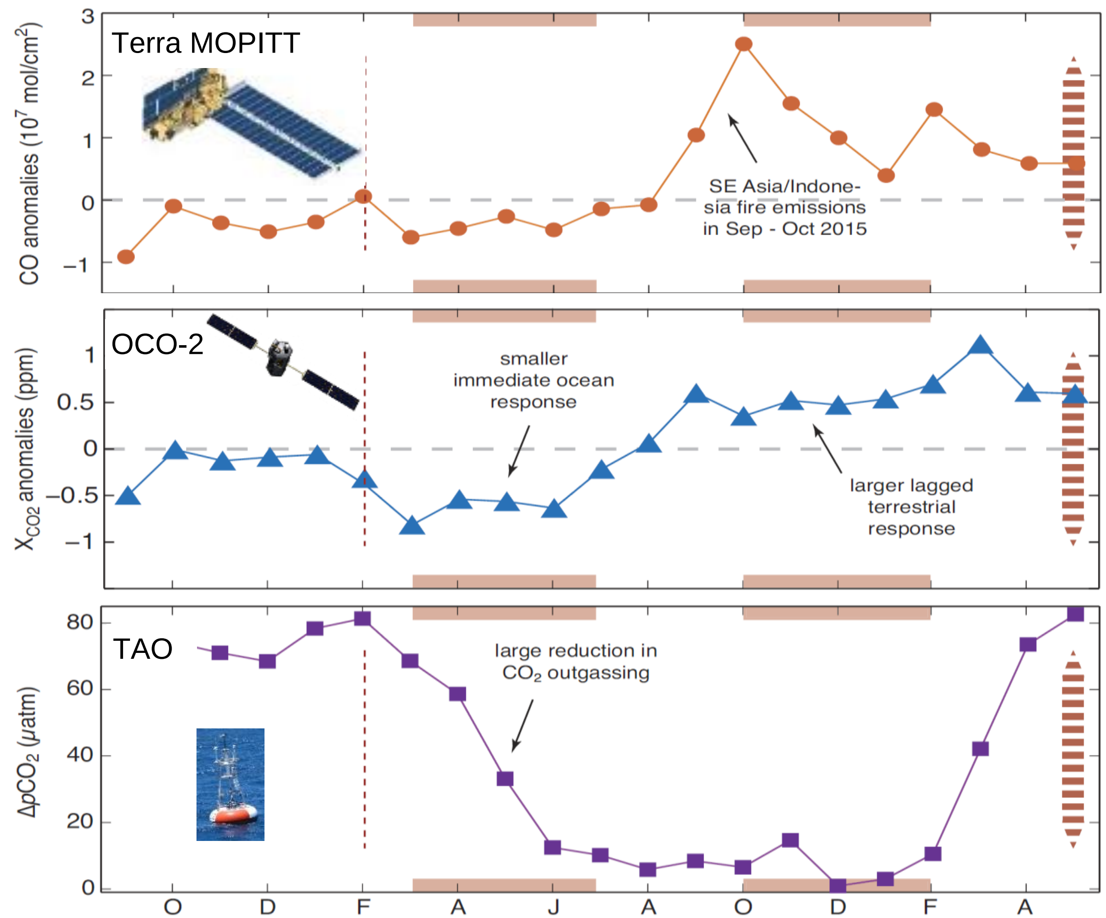
Anthropogenic Emissions



Janne Hakkarainen et al. GRL (2016)

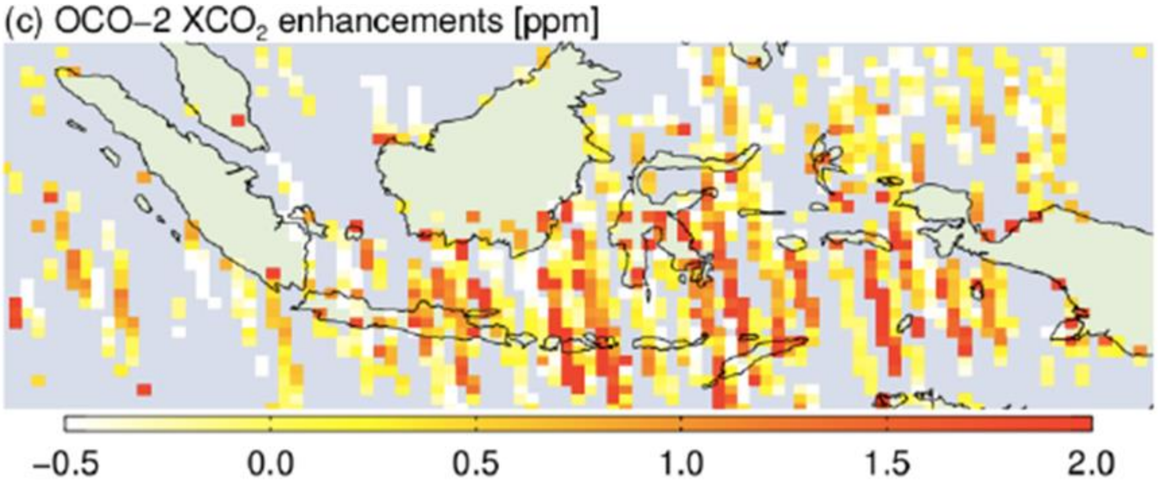
2015-2016 El Niño: Ocean Response

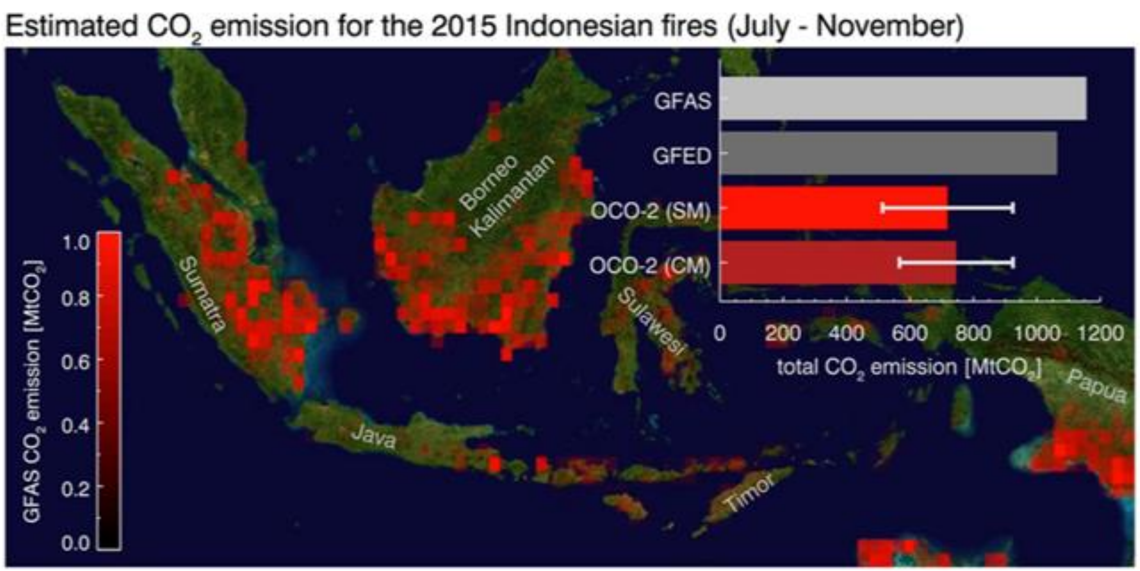




Abhishek Chatterjee et al. (submitted)

2015-2016 El Niño: Fires



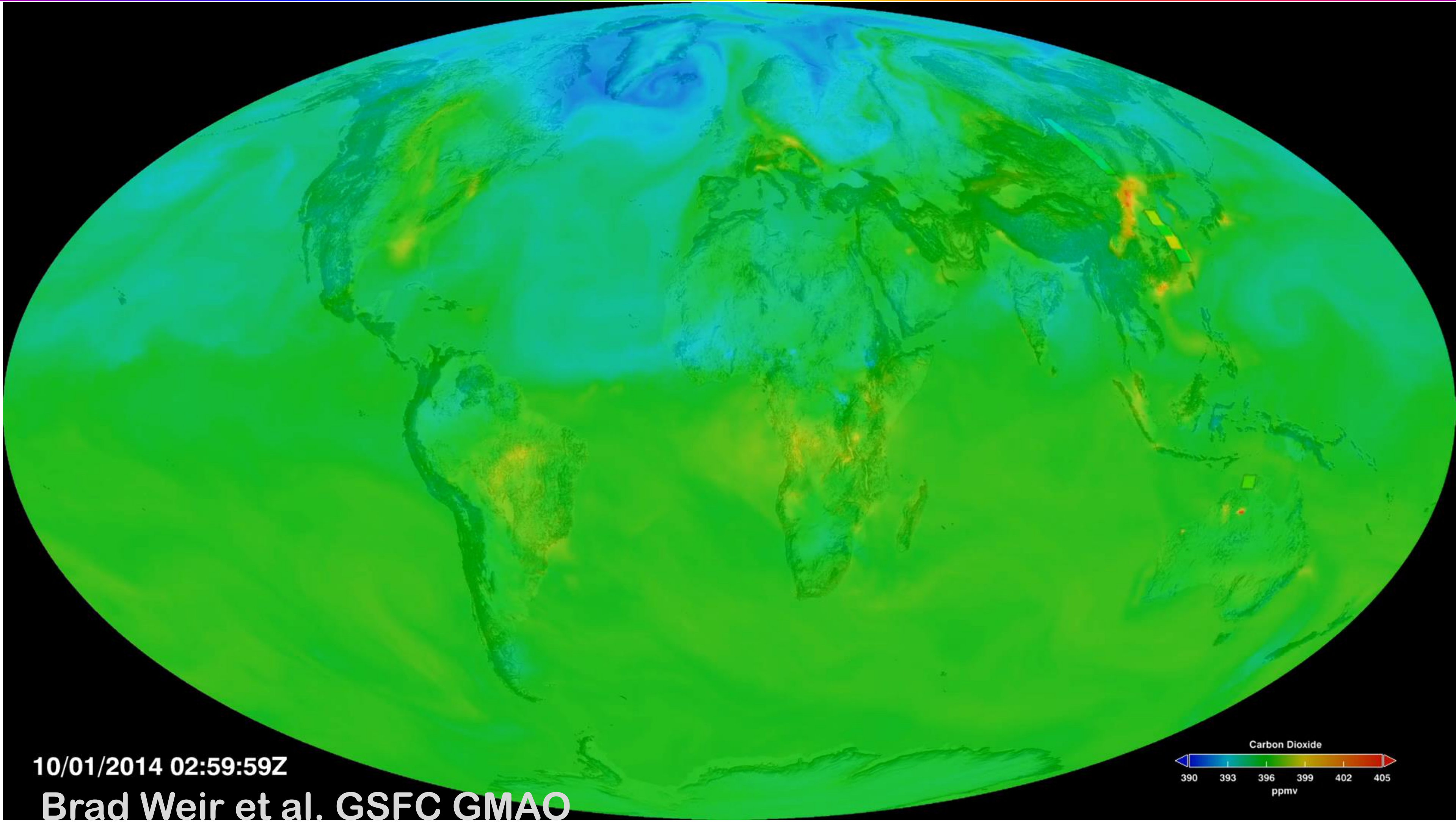


Jenns Heymann et al. (GRL, Accepted 2017)

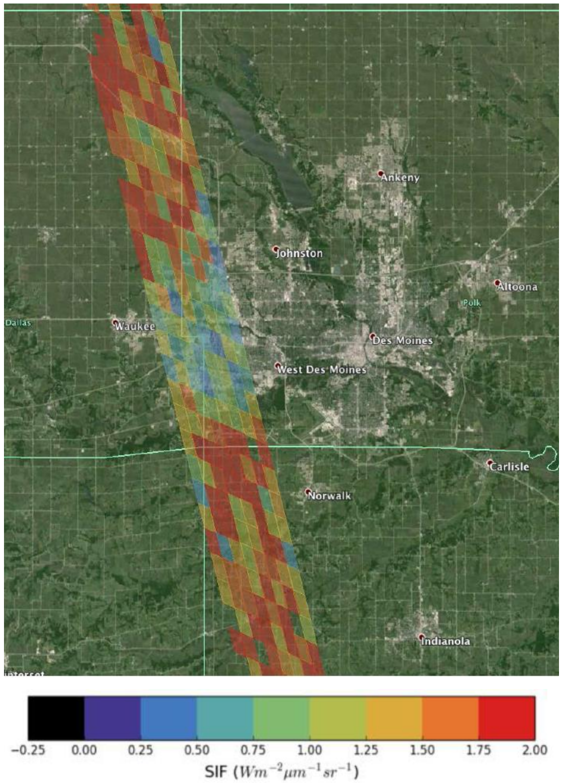
X_{CO2} enhancements over Indonesia observed by OCO-2 between July and November 2015.

Fire emissions estimates from the GFAS and GFED inventories to emission estimates obtained from OCO-2 data, using two analysis approaches. The OCO-2 estimates are less than 70% as large as those in the inventories.

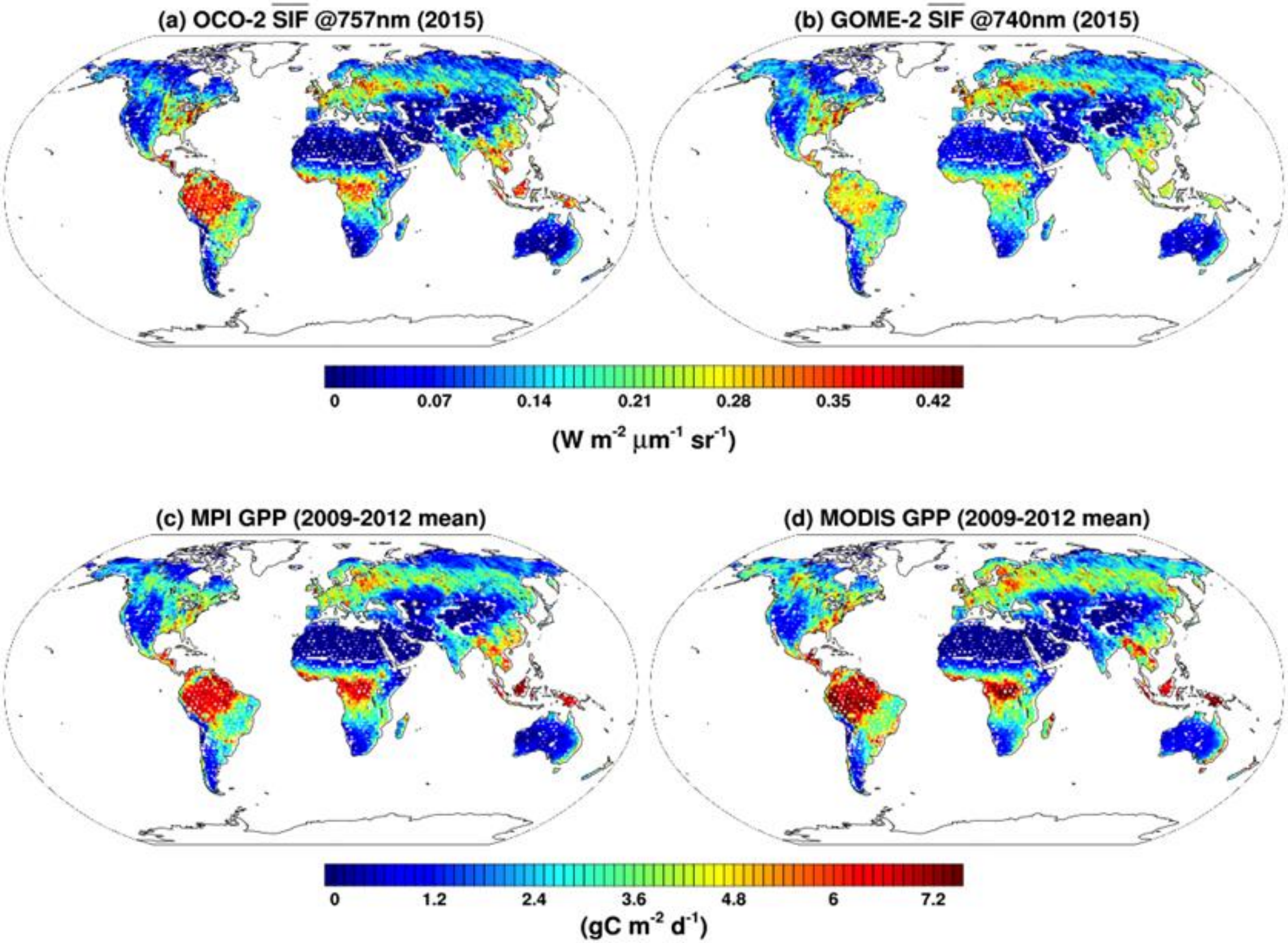
Assimilation of OCO-2 X_{CO2}



Solar Induced Chlorophyll Fluorescence (SIF)



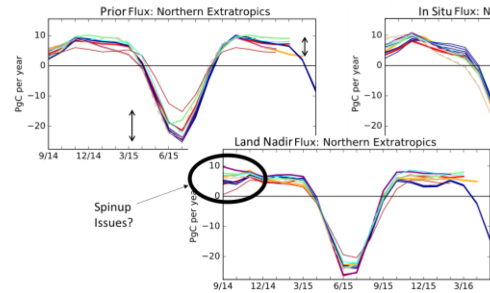
OCO-2 SIF over Des Moines, Idaho



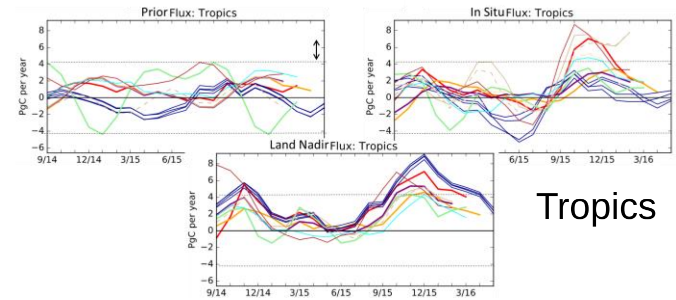
Ying Sun et al. (submitted 2017)

Global Flux Inversions

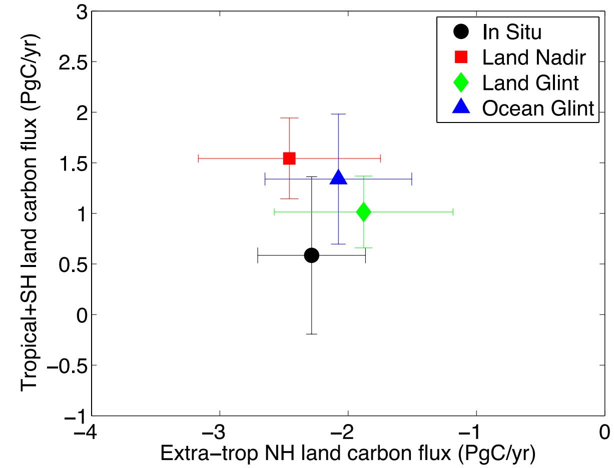
- Over the past year, the flux group made tremendous progress understanding how OCO-2 data inform flux estimates at large spatial scales
- Biases in observations are driving unrealistic flux behavior, but we are on the path of imposing post-hoc corrections to address the biases inside the inversions
- OCO-2 fluxes are providing insight into the impacts of the recent El Nino on the carbon cycle
  - Excellent agreement in results in the regions with the signals of interest.



NH Extratropics

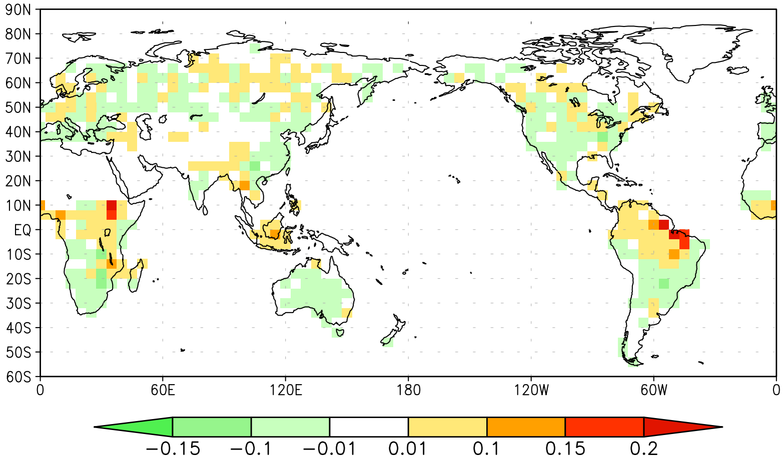


Tropics

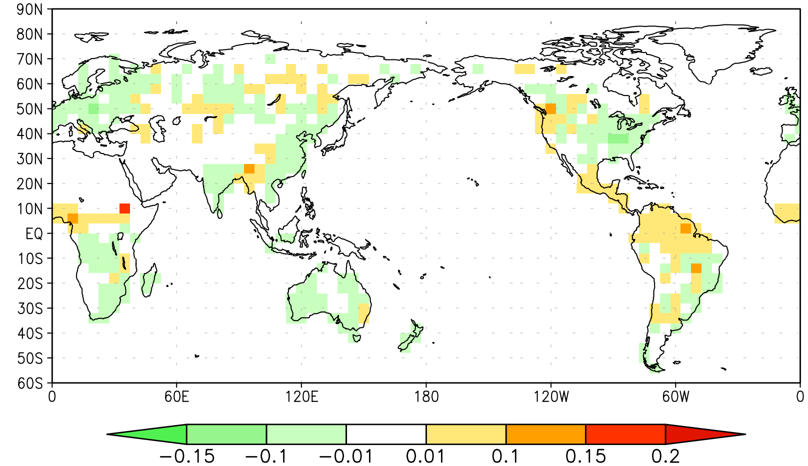


2015 El Niño and 2011 La Niña annual biosphere fluxes and their differences

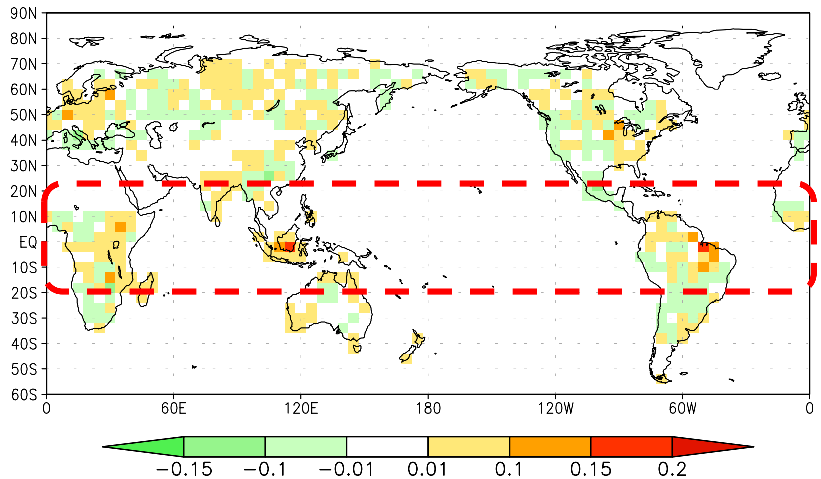
2015 (GtC/yr)



2011 (GtC/yr)



2015- 2011 (GtC/yr)



Red: release CO_2 into atmosphere

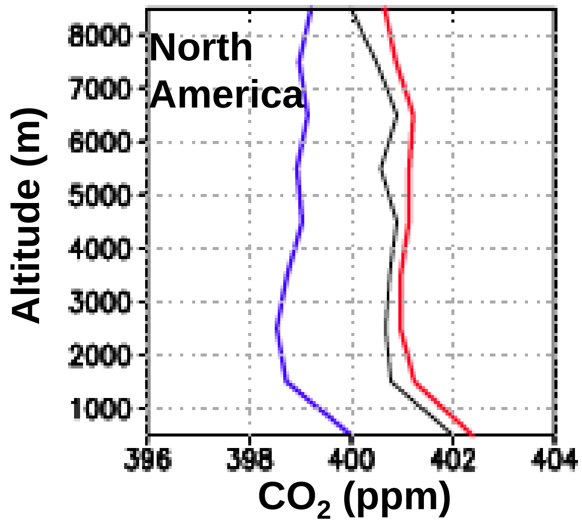
Green: absorb CO_2 from atmosphere

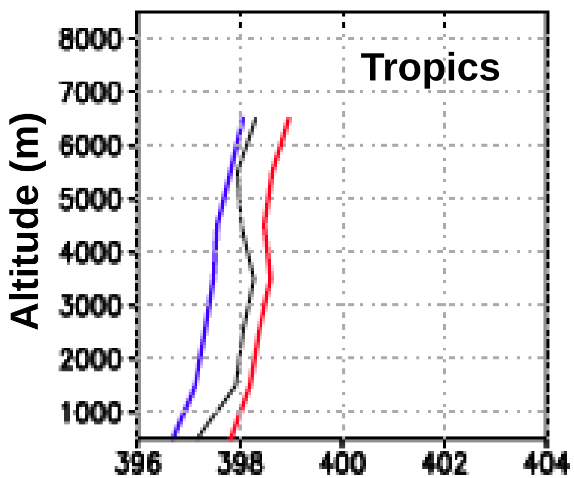
- **The most significant impact of 2015 El Niño on biosphere carbon fluxes is the increase of CO_2 release from the tropics**

Junjie Liu et al. (Submitted 2017)

Validating Regional Flux Changes

Aircraft vs OCO-2

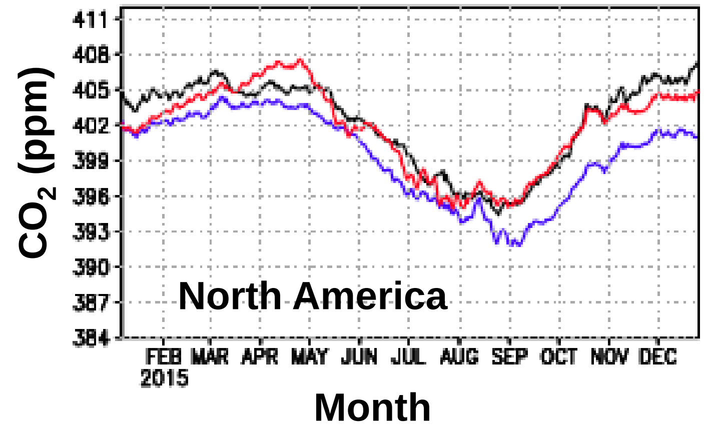


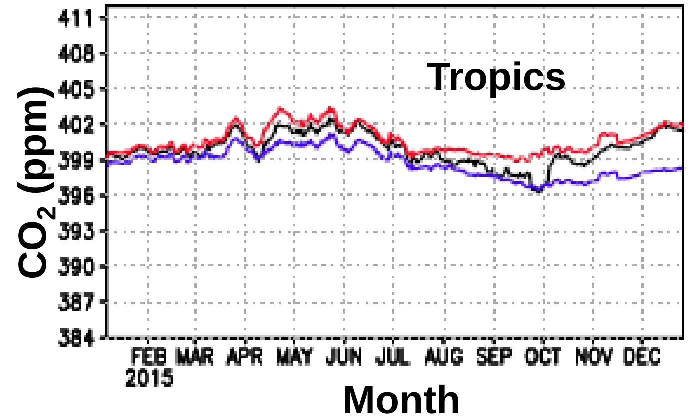


Junjie Liu et al. compare modeled profiles derived in their studies to aircraft and modeled in situ surface values to flask in situ measurements

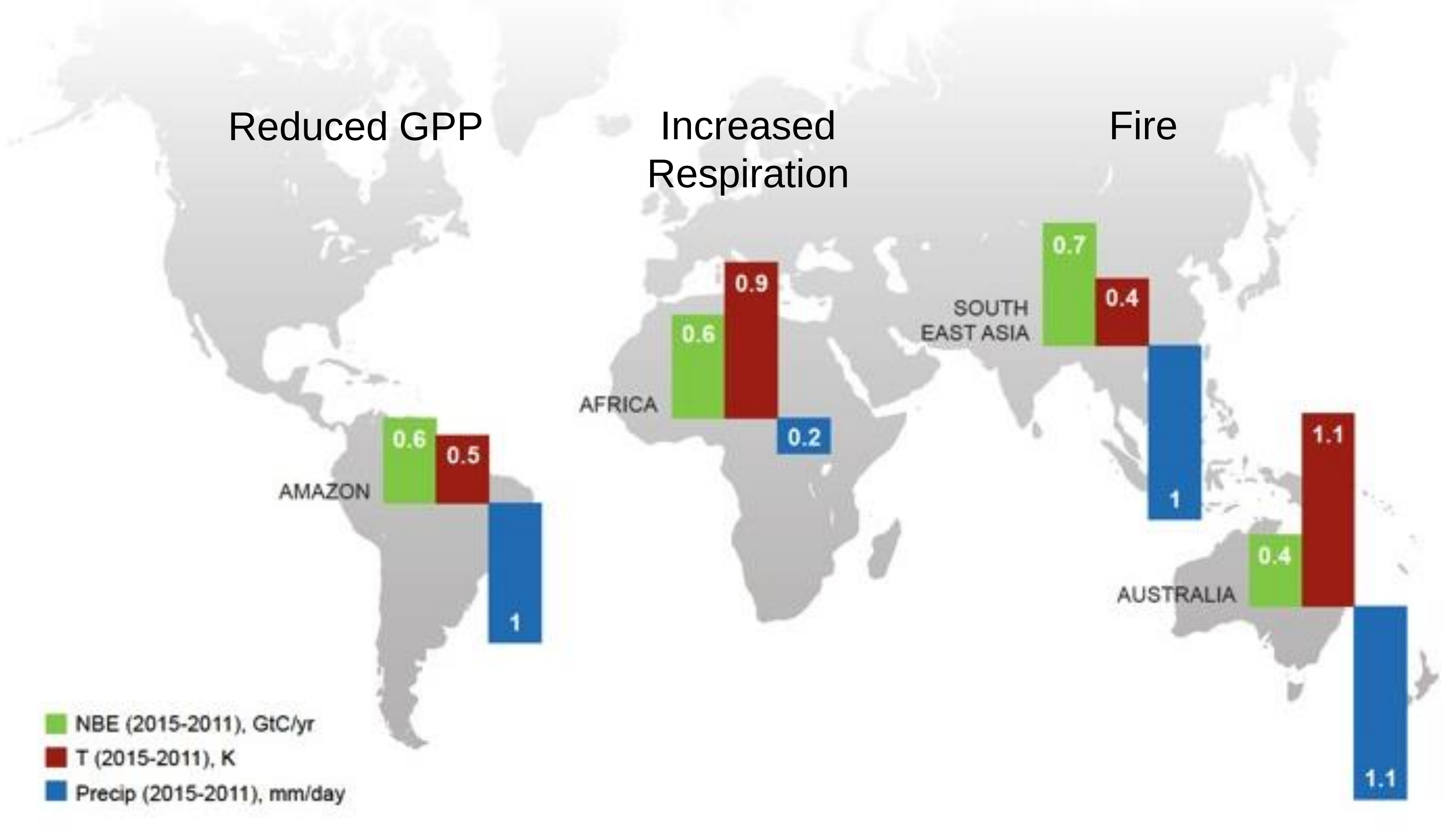
- Blue: model prior
- Red: model posterior
- Black: in situ observation

Surface Flask vs OCO-2





2015-2016 El Niño: 3 Continents, 3 Stories

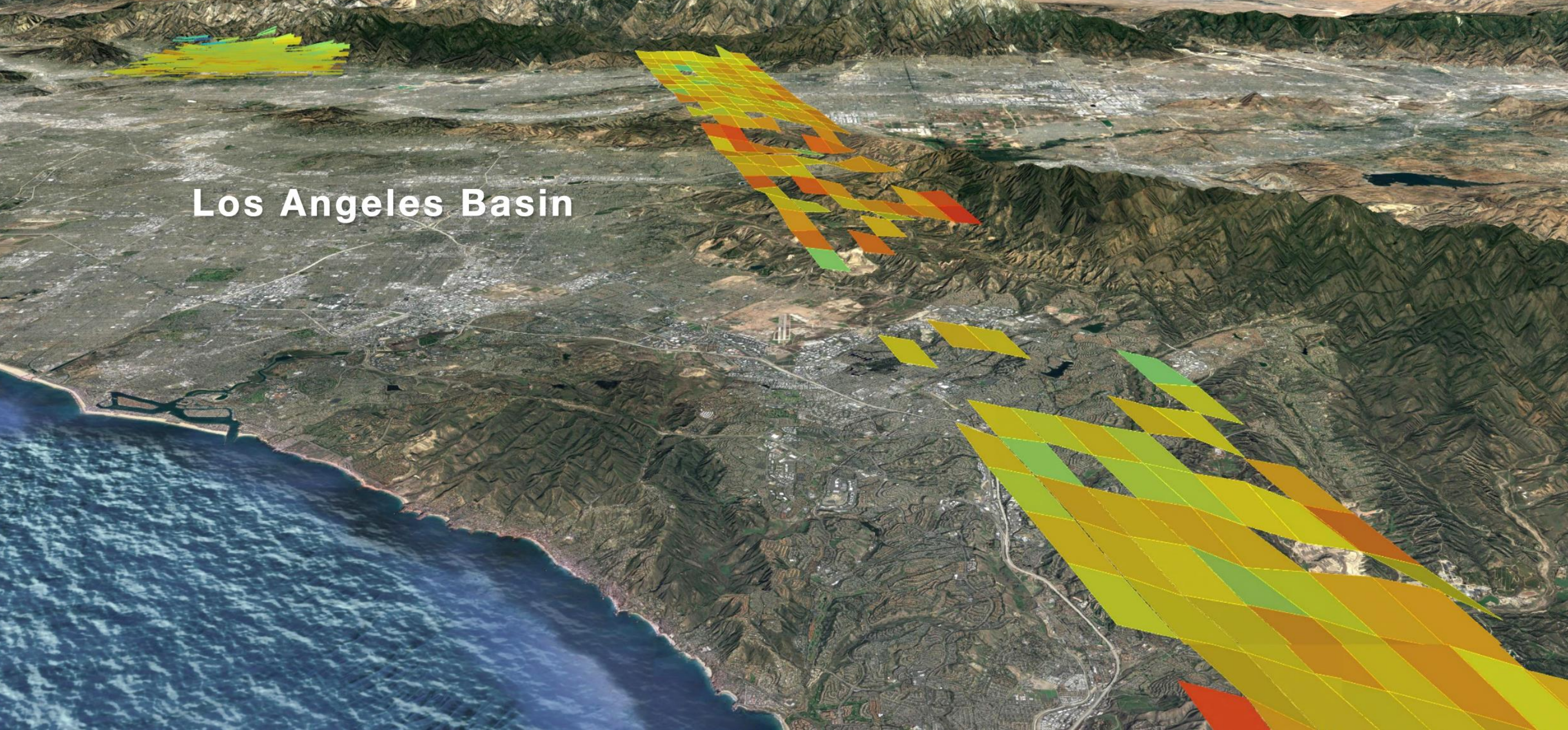


New Missions

TanSat Status

Introduction to Gaofen-5

Introduction to GeoCarb



TanSat Status

- TanSat was successfully launched on 22 December 2016
  - Launch included the TanSat satellite and 3 microsatellites
  - Initially inserted into a 1:30 PM sun-synchronous orbit 2.5 km above the A-Train. A-Train insertion still possible but plans are unknown
- Yi Liu attended the 9th GEOSS Asia Pacific Symposium and the AMS meeting
  - Reported that the in-orbit check-out was going as planned
  - First light spectra were acquired a day or two before the Jan 24 AMS talk
- They still plan to distribute the data, but the schedule is unknown

Term-1(2011-2015)
Measurement Goals
XCO2
1~4 ppmv
Monthly
500 x 500 km^2

Term-2(2013-2015)
Measurement Goals
CO2 Flux
Relative flux error
20%
Monthly
500 x 500 km^2

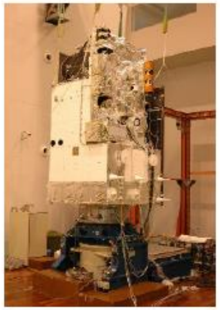
	O2-A	CO_2 weak	CO_2 Strong
Spectral Range (nm)	758-778	1594-1624	2041-2081
Spectral Resolution	0.044	0.12(0.081)	0.16(0.103)
SNR	360	250	180
Spatial Resolution	1km×2km, 2km×2km		
Swath	20km		

Yi Liu, 9th GEOSS Asia Pacific Symposium

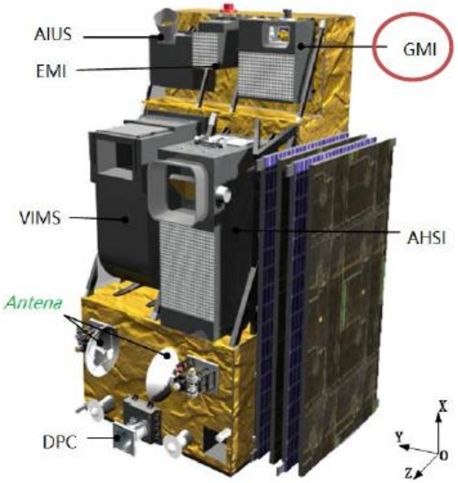
Gaofen 5 Satellite (GF-5)

- **Yi Liu also confirmed that the GF-5 satellite will launch later this year, carrying the GMI instrument, which will measure CO_2 and CH_4 as well as a suite of other instruments**

Orbital Type	Sun synchronous orbit
Orbital altitude	708 km
Local time	1：30



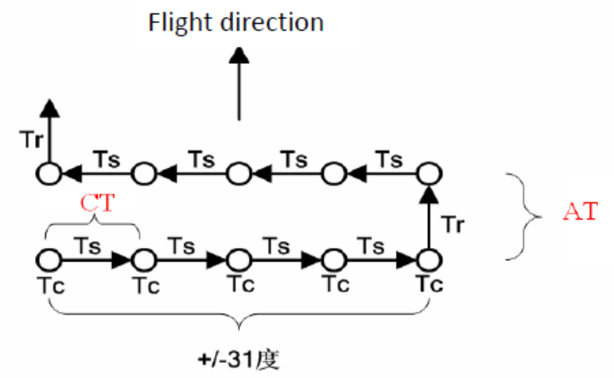
Sensors onboard GF-5
● Advanced Hyperspectral Imager (AHSI)
● Visual and Infrared Multispectral Sensor (VIMS)
● Greenhouse-gases Monitoring Instrument (GMI)
● Atmospheric Infrared Ultraspectral (AIUS)
● Environment Monitoring Instrument (EMI)
● Directional Polarization Camera（DPC）



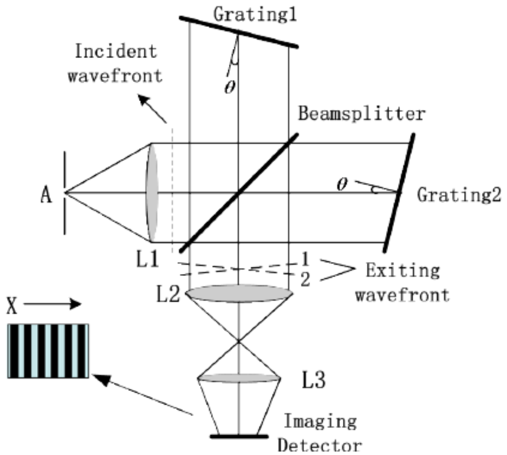
Yi Liu, 9th GEOSS Asia Pacific Symposium

GF-5 GMI Specifications

	technical parameters			
	O_2	CO_2	CH_4	CO_2
Central wavelength(um)	0.765	1.575	1.65	2.05
Band width(um)	0.759-0.769	1.568-1583	1.642-1.658	2.043-2.058
Spectral resolution	0.6cm^{-1}	0.27cm^{-1}		
SNR	300@ =30%		250@ =30%	
Radiation calibration	5% (relative, ~2%)			
Size	790mm (X) ×690mm (Y) ×575mm (Z)			
Field of view	14.6mrad IFOV<10.3km@708km			
Sample	5、7、9-points			
Observation mode	nadir(mainly)/glint			
Weight	109kg			
Power	120W			
Data transfer rate	30Mpbs			



Observation patterns	Along track direction AT (km)	Across-track direction CT (km)
1		
5	100	212
7	130	142
9	130	106



The specifications and observing strategy of the GF-5 GMI instrument are very similar to those of the GOSAT mission, but GMI uses a Spatial Heterodyne Spectrometer rather than an classical Michaelson Interferometer

Yi Liu, 9th GEOS Asia Pacific Symposium

The Earth Ventures GeoCarb Mission

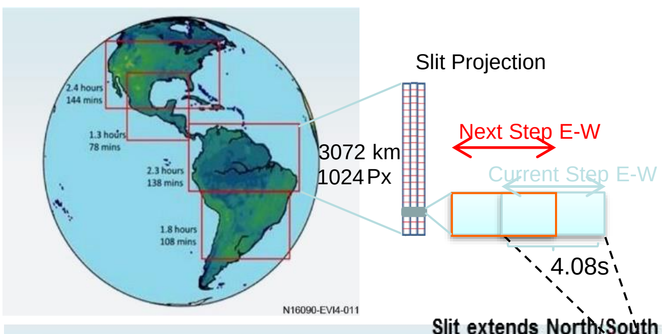
- NASA selected the Geostationary Carbon Cycle Observatory (GeoCarb) Project as the 2nd Earth Ventures Mission
- GeoCarb is the first NASA satellite designed to collect spatially resolved observations of X_{CO2}, X_{CH4}, X_{CO} and solar induced chlorophyll fluorescence (SIF) from geostationary orbit (GEO)
- The Principal Investigator (PI) of the GeoCarb mission is Professor Berrien Moore of the University of Oklahoma
- Mission partners include
  - Lockheed Martin Advanced Technology Center in Palo Alto, CA
  - SES Government Solutions Company in Reston, Virginia
  - Colorado State University in Fort Collins, CO
  - NASA's Ames Research Center in Moffett Field, CA
  - Goddard Space Flight Center in Greenbelt, Maryland
  - Jet Propulsion Laboratory, Caltech, Pasadena, CA

GeoCarb Sampling

GeoCarb Sampling

High Spatiotemporal Resolution
Daily/Sub-daily Revisits
Flexible Scanning Strategies

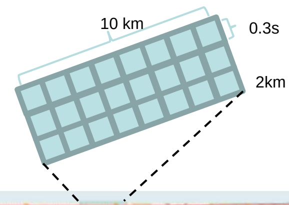
Fixed
FOV
Land only

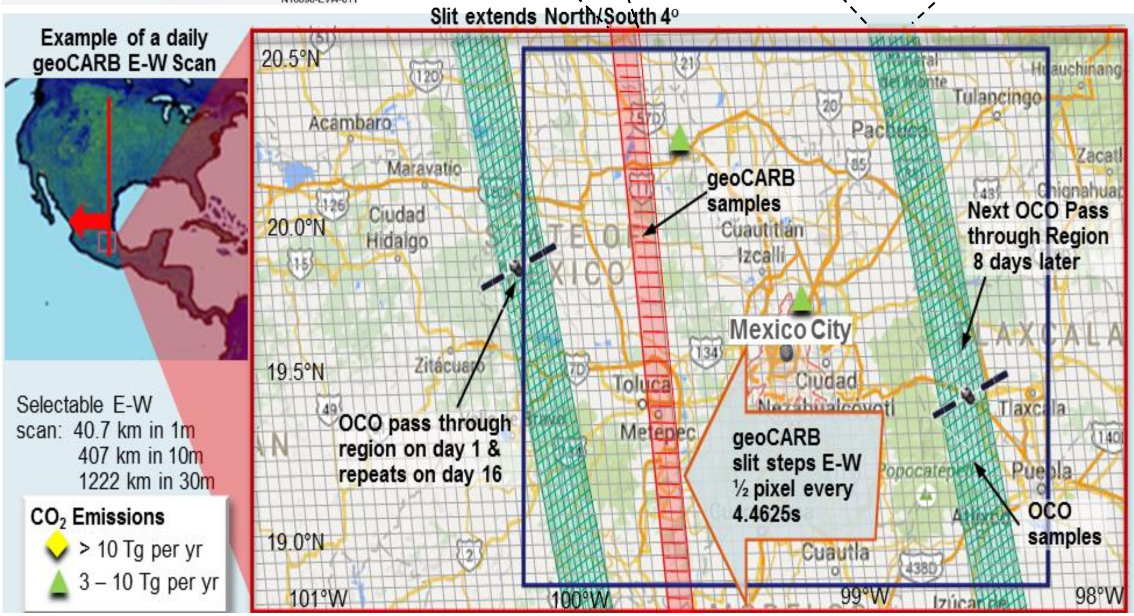


OCO-2 Sampling

High Spatial Resolution Along Track
8 Footprints for Small Scale Variability
Global Land/Ocean Coverage

16 Day Revisit Cycle
Large Gaps Between Tracks





The geoCARB instrument will be hosted on a SES Government Solutions satellite in GEO orbit at 85° West longitude.

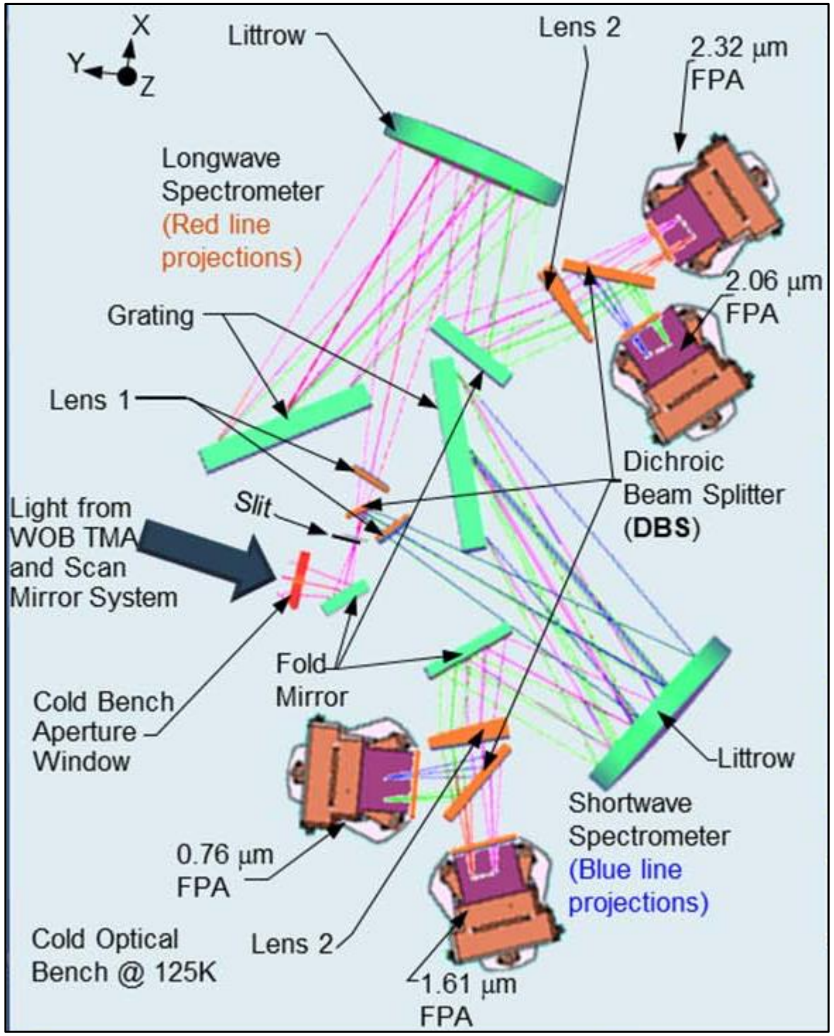
From this vantage point, the GeoCarb instrument will produce maps of the CO_2, CH_4, and CO concentrations and SIF at a spatial resolution of 5-10 km multiple times each day.

GeoCarb Instrument Design

GeoCarb employs a four channel grating spectrometer that measures reflected sunlight in four bands:

- **0.76 µm (O_2 and SIF)**
- **1.61 µm (CO_2)**
- **2.06 µm (CO_2)**
- **2.32 µm (CO and CH_4)**

Instrument model studies and OSSEs were performed to tie signal and noise characterizations and science objectives to realizable and scientifically useful



Evolving Carbon Measurement Capabilities

- TanSat Successfully Launched on 22 Dec 2016
- NASA Earth Ventures GeoCarb Selected
- CNES MicroCarb Approved for Implementation

Upcoming Activities

- 21-23 March: OCO-2 Science Team Meeting, Caltech, Pasadena, CA
- 27-30 March: North American Carbon Program, Bethesda, MD
- 10-13 April: GAW Symposium, WMO, Geneva
- 19-21 April: A-Train Symposium, Pasadena, CA
- 23-28 April: EGU, Vienna
- 20-25 May: JpGU, Chiba, Japan
- 6-8 June: IWGGMS, Helsinki
- 28-30 June: CEOS VC-AC, CNES HQ, Paris
- 6-11 August, AOGS, Singapore
- 21-25 August, ICDC10, Interlaken, Switzerland